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U. S. DEPARTMENT OF AGRICULTURE
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CHARLES F. MARVIN, Chief

MONTHLY WEATHER REVIEW

VOLUME 48, No. 3

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INTRODUCTION.

The MONTHLY WEATHER REVIEW contains (1) meteorological contributions, and bibliography including seismology; (2) an interpretative summary and charts of the weather of the month in the United States and on the adjacent oceans; and (3) climatological and seismological tables, dealing with the weather and earthquakes of the month.

The contributions are principally as follows: (*a*) Results of the observational or research work in meteorology carried on in the United States or other parts of the world, in the Weather Bureau, at universities, at research institutes, or by individuals; (*b*) abstracts or reviews of important meteorological papers and books, and (*c*) notes. In each issue of the REVIEW reviews, abstracts, and notes are grouped by subjects, roughly, in the following order: General works, observations and reductions, physical properties of the atmosphere, temperature, pressure, wind, moisture, weather; applications of meteorology, climatology, and seismology.

The Weather Bureau desires that the MONTHLY WEATHER REVIEW shall be a medium of publication for contributions within its field, but **the publication of contributions is not to be construed as official approval of the views expressed.**

The partly annotated bibliography of current publications is prepared in the Weather Bureau Library. *Persons or institutions receiving Weather Bureau publications free should send in exchange a copy of anything they may publish bearing upon meteorology, addressed "Library U. S. Weather Bureau, Washington, D. C.,"* in order that the monthly list of current works on meteorology and seismology may be as complete as possible. Similar contributions from others will be welcome. Bibliographies of selected subjects are published from time to time in the REVIEW or SUPPLEMENTS.

The section of the weather of the month contains (1) an interpretative discussion of the weather of North America and adjacent oceans, and some notes on the weather in other parts of the world; (2) details of the weather of the month in the United States; and (3) brief discussions of weather warnings, rivers and floods, and weather and crops. There are illustrative charts. The climatological tables comprise summaries of the weather and excessive precipitation data for about 210 stations in the United States, and summaries of the weather observed at about 30 Canadian stations.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are due especially to the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
Meteorological and Seismological Service of Mexico.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, Petrograd.
The Philippine Weather Bureau.

The seismological tables contain, in a form internationally agreed on, the earthquakes recorded on seismographs in North and Central America. Dispatches on earthquakes felt in all parts of the world are published also.

Since it is important to have as the name of the month appearing on the cover of the REVIEW that of the period covered by the weather discussions and tables rather than that of the month of issue, the REVIEW for a given month does not appear until about the end of the second month following.

SUPPLEMENTS containing kite observations and others containing monographs or specialized groups of papers are published from time to time.

NOTES TO CONTRIBUTORS.

Authors are requested to accompany their papers submitted for publication with a brief opening synopsis. When an article deals with more than one subject—as, for example, a method of measurement—some experimental results and a theory, each subject should be summarized in a *separate paragraph*, with a title which clearly describes it.

When illustrations accompany an article submitted for publication in the MONTHLY WEATHER REVIEW, the places where they should appear in the text should be indicated, and legends or titles for them should be inserted just after the end of the article. As far as practicable the illustrations when accompanied by their legends should be self-explanatory—i. e., the data on them should leave no doubt of what they are intended to convey.

BACK NUMBERS OF THE REVIEW WANTED.

As the surplus of MONTHLY WEATHER REVIEW, February, April, June, July, and August, 1919, is exhausted, recipients who do not care to retain their copies will confer a favor by using attached addressed, franked slip. The return of other issues of 1919 and earlier years will also be appreciated.

MONTHLY WEATHER REVIEW

CHARLES F. BROOKS, Editor.

VOL. 48, NO. 3. MARCH, 1920. CLOSED MAY 4, 1920
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RELATION OF CHANGES IN STORM TIDES ON THE COAST OF THE GULF OF MEXICO TO THE CENTER AND MOVEMENT OF HURRICANES.

By ISAAC M. CLINE, District Forecaster.

[Weather Bureau, New Orleans, La., Mar. 10, 1920.]

SYNOPSIS.

A brief summary of what is known bearing directly on this subject concerning wind and waves is given.

Hurricanes are in all instances preceded by storm tides. The water commences rising on the coast in front of the cyclonic area, one to two days before the storm in experienced.

The wind velocities and directions in different parts of the hurricane, as deduced theoretically, do not meet the requirements in this study to explain the rises in tides. Composite charts showing the actual wind directions and velocities determined from stations in the different parts of the cyclonic area are submitted. In the right-hand rear quadrant the winds blow with much greater velocity and persist in the same direction longer than in any other part of the hurricane. At stations in this quadrant the wind has been found to blow for 24 hours or longer with a direction in line with the advance of the hurricane, with an average velocity of 60 miles per hour, and for 13 hours at 70 to 85 miles per hour. In other parts of the cyclonic area the wind continues to blow over the water in the same direction for only a few hours.

Winds in the cyclonic area over water develop waves of a size and length which bear a relation to the sustained velocity of the wind and the length of time the waves are under the influence of the same wind direction. Waves of different sizes are developed in proportion to the winds which prevail in the different parts of the cyclonic area. The largest and longest waves are created in the rear right-hand quadrant; these waves pass on through the cyclonic area and move to shore where they cause a rise in the water in the front of and on the right of the line over which the center of the hurricane is advancing. This rise begins when the center of the hurricane is 300 to 500 miles distant, and continues until the hurricane moves inland. The heights of the water reached at shore near the center of the storm vary from 8 to 15 feet above mean Gulf level.

Changes in the position of the rise of the storm tide indicate changes in the course of the storm.

Bold-face figures in parenthesis refer to authorities preceded by the same figure in the bibliography at the end of this paper.

STORM WAVES AND SWELLS.

Waves and tides that appear along our coasts, many hours and at times one or two days in advance of hurricanes, convey some definite information regarding the position and direction of movement of the storm still many miles distant in the Gulf. Swells and waves break upon the shore and the water rises as the result of winds prevailing in the Gulf sometimes 400 to 500 miles distant.

The relations which the movements and actions of the waves and tides bear to the position and movement of the meteorological disturbances, which develop and carry these phenomena to shore, have not received the attention the importance of the subject justifies.

Ocean waves and their action under winds have received the attention of investigators, and we will summarize briefly the more important results obtained that bear directly on this subject. Their height, length, and speed have been carefully studied and recorded in both deep and shallow water. In the Atlantic and other oceans with 600 to 1,000 miles sea room it has been found in ordinary storms that waves of 35 to 40 feet in height are developed and in exceptional storms waves may exceed 45 feet. The crossing of two large waves will sometimes send up a peak of water which has been estimated to be 50 to 55 feet in height. The quotient obtained by dividing the wind velocity in miles per hour by 2.05 represents the average height in feet of the waves developed by that wind; however, this average will be exceeded when the wind has full opportunity to exert its force. Waves produced upon the deep sea communicate their motion to the water to a depth of about one-fourth the wave length; when the waves run into water which has depth less than one-fourth the wave length a reduction of the speed of the wave results and continues as shallower water is reached; the diminishing speed causes the wave crests to close up, the space separating them becomes less and less as the depth of the water diminishes; but the interval of time between the arrival at shore of successive crests remains unchanged. The average storm wave in deep water moves forward with a velocity a few miles per hour less than the wind velocity that produces it. Long waves and swells that move through the storm and break upon the shore travel when in deep water with a greater speed than the highest waves in storms travel. In seas partly inclosed the speed and length of waves are less than on the open ocean, these being determined by the length of fetch as well as winds. (3.)

In the Gulf of Mexico there is a distance or length of fetch over deep water for 600 miles from the Yucatan Channel to the middle Gulf coast and 800 miles to the west Gulf coast. From the Florida Straits to the middle and west Gulf coast the distance or length of fetch ranges from 600 to 1,000 miles.

In a cyclonic area with a progressive movement of 12 to 15 miles per hour large waves of considerable length are driven through and beyond the cyclonic area and by gravity and inertia are carried on far in advance of the area covered by the cyclonic circulation.

In discussing the propagation of waves of the sea in this connection Cornish says: (6)

> The breakers which arrive (at shore) somewhat irregularly during storms do so at intervals which, as far as I have noticed them, do not differ much from the intervals observed on board ship in the deep sea during storms. When waves are driven outside the wind area and left to themselves to travel over considerable distances the originally complex and irregular waves are analyzed into a series

of simple, regular waves of graduated lengths. The longer and swifter are in front, the shorter and slower in the rear; the shorter components flatten out very quickly as they travel, whereas the longer components preserve their height with but little diminution for long distances and reach places far distant from the windward shore, where the water will heave with a long period undulation. At a considerable distance from the windward shore the state attained by the sea during a storm does not depend only on what the wind does there but by the transmission by gravity, independently of the wind of the longer-period component of the irregular waves which the storm has created to windward. The greater the length of the fetch the greater is the distance from which the surface water draws the reinforcement of its long period heaving and the greater, therefore, is that part of the wave disturbance which is of greater wave length than the dominant wave.

Darwin says: (2)

The point we have to note is that an isolated disturbance will generate long waves and they will run ahead of the small ones; the long waves are more persistent, * * * but I do not understand how it is that the separation of the long from the short waves is so complete nor what governs the length of the wave.

Dr. George Stokes showed nearly half a century ago that there is a transfer of water in the direction in which the wave is moving. The speed of the transfer depends on the depth and diminishes rapidly as the depth of the water increases. (4)

Coast currents observed as resulting from cyclonic storms in the Bay of Bengal have a steady set or drift to the west. Eliot says: (1)

It is probable that the strength of a cyclone advancing to the northward coast of the bay could be roughly ascertained by the strength of the westerly set at the head of the bay. Data are, however, wanting to test this. * * * The drift near the center of large storms in the Bay of Bengal may be so much as 6 to 8 knots * * *.

Observations of construction engineers indicate that the effects of waves on such structures as rubble breakwaters are generally not appreciable beyond a depth of 15 to 16 feet below the water surface. This varies, however, in different localities. At Port Elizabeth, South Africa, blocks of rubble stone weighing 100 to 150 pounds, in 22 feet of water, were not disturbed by waves 15 to 20 feet high. At Colombo stones weighing three tons, in water 10 to 14 feet deep, were disturbed by waves not exceeding 15 feet in height. At Algiers, Africa, stones 33 to 39 feet below the surface of the water were moved by waves or currents.(7)

The most destructive element in hurricanes is the breaking wave. A cubic yard of water weighs about 1,500 pounds and the waves, driven by the wind, break on the coast with the water moving forward at a speed of many feet per second, and cause destruction which exceeds description.

TIDE RECORDS.

The Port Eads tide gage is about 2½ miles up the South Pass from the Gulf, and the Burrwood gage in Southwest Pass is 5 miles from the Gulf.

The tide gage at Galveston is at the foot of Twentieth Street. The tide records used with the Mobile (Ala.) meteorological records are Pascagoula, Miss., 1909, and for the other years, Fort Morgan, Ala.

Mean low water at Port Eads, La., is 0.3 of a foot and at Burrwood, La., is 0.7 of a foot above mean Gulf level. At Fort Morgan, Ala., mean low water is 0.3 of a foot above mean Gulf level. For Galveston the United States Coast and Geodetic Survey gives mean low water (1917) 0.5 of a foot below mean Gulf level.

The zero of the tide gage at Port Eads, La., is 3.16 feet and at Burrwood, 2.26 feet below mean Gulf level, and at Fort Morgan, Ala., the zero of the tide gage is 1.22 feet below mean Gulf level; therefore, mean low water on the Port Eads gage reads 3.46, on the Burrwood gage 2.96, and on the Fort Morgan gage, 1.52.

Darwin, in speaking of tides, says: (2) "The word 'tidal' should only be used when we are referring to regular and persistent alternations of rise and fall of sea level." He suggests that changes of water level due to wind and other atmospheric influences should be referred to as a "meteorological tide." The meterological tide may be either low water or high water.

In referring to tides generally, mean low water as used by the United States Coast and Geodetic Survey will be used as the reference plane. The tide graphs shown with the graphs of meteorological conditions will give the tides above mean low water, in order that the records for Galveston, Burrwood, and Mobile, may be easily compared as the cyclonic area advances.

The term "Storm tide" will be used to represent the height of the water in excess of the predicted tide at a given hour. A study of the relationship existing between hurricanes and tides has been made possible through the complete records of tide conditions which we have had the good fortune to secure for this study.

Each hurricane, during the 20 years, 1900 to 1919, inclusive, will be taken up in chronological order, and we will deal especially with the relation of the tides to the center and movement of the hurricane.

METEOROLOGICAL RECORDS AND HURRICANE TIDES.

September 1–12, 1900.—This disturbance reached the Florida Straits, September 5, and moved in a northwesterly direction across the Gulf, a distance of nearly 1,000 miles, with its center passing inland over the western part of Galveston Island about 9 p. m., September 8. A graphical representation of the wind, barometric pressure, and tides at Port Eads, La., and Galveston, Tex., during the passage of this storm through the Gulf is shown in Plate I. At Port Eads the barometer commenced falling on the morning of the 6th and fell steadily until the night of the 7th, when 29.56 was recorded at the 8 p. m. observation. The wind was from the northeast during the 6th and until 8 a. m. of the 7th, with steadily increasing velocity, but not exceeding 44 miles per hour. The wind shifted to the east in the afternoon of the 7th, and the highest hourly velocity was 47 miles at 4 p. m. and 5 p. m. At 8 a. m. the wind was from the southeast and the velocity 30 miles per hour.

The tide gage at Port Eads showed a slight rise in the water above the regular tides during the 6th, and the water continued to rise steadily, reaching 2.8 feet above mean low water at 9 p. m. on the 7th, the rise caused by the hurricane in 24 hours being 1.2 feet. The oscillations of the regular tides were not overcome, but the water at lowest tide on the afternoon of the 7th was 1.6 feet higher than the lowest water on the previous day. Port Eads was about 150 miles to the right of the line of advance of the center of the hurricane at the time of the highest water. In this instance the water at shore commenced rising at Port Eads 150 miles to the right of the line of advance of the hurricane, when the center was 400 miles distant and 36 hours before that place was on a line drawn through the center of the hurricane at right angles to the line of advance. The highest water occurred with the passage of the center of the cyclonic area and coincident with the lowest barometer and highest winds.

At Galveston the barometer commenced falling at 5 p. m. on the 6th and continued falling steadily, but slowly, up to noon of the 8th, when it read 29.42 inches. The barometer then fell rapidly, recording 28.48 inches

at 8:30 p. m. of the 8th, the lowest pressure recorded up to that time at a Weather Bureau station. The wind blew steadily from the north from noon of the 6th until 3 p. m. of the 8th, except that it blew from the northeast during the hours ending at 9 a. m. and 10 a. m. of the 8th. The prevailing wind was from the northeast from 3 p. m. to 8:30 p. m., September 8; east from 8:30 p. m. to 10 p. m., southeast from 10 p. m. to 11 p. m., and after that time from the south. The wind velocity was

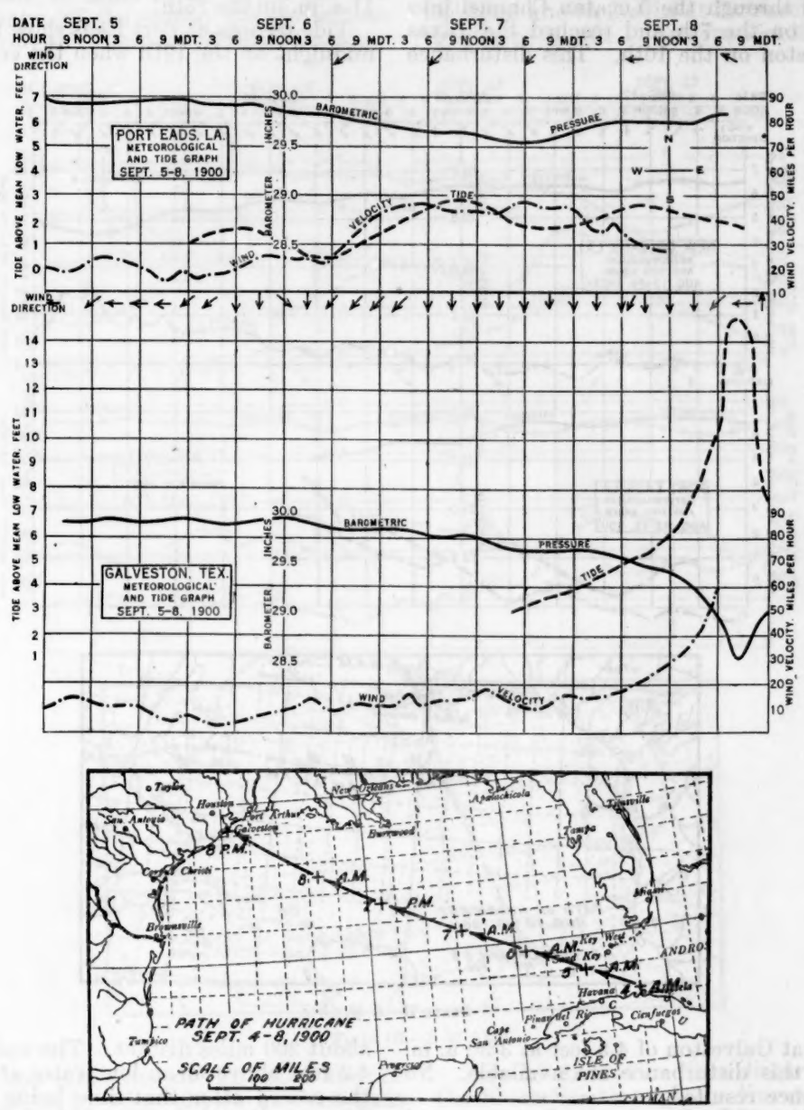


PLATE I.—*I. M. Cline.*

less than 20 miles per hour up to 6 a. m. of the 8th, after which the velocity increased steadily, reaching 30 miles per hour at noon of the 8th, and was 60 miles during the hour ending 6 p. m. when the anemometer blew away. The velocity was increasing rapidly at that hour, 2 miles having been recorded at the rate of 100 miles per hour. It is estimated that a velocity of 120 miles per hour was reached about the time of the shift of the wind to the east.

There are no tide observations at Galveston prior to 4 p. m. of the 7th, when the water already stood 3 feet above mean low tide, showing nearly 2 feet of storm tide. At this time the center of the hurricane was 300 miles distant in space and 30 hours in time, and its line of advance was toward Galveston. The water stood one foot higher at Galveston at this hour than at Port Eads, which was only about 175 miles distant, from the cyclonic center, to the right of the line over which it was advancing. The crest of high water at Port Eads was 2.8 feet, and was reached at 9 p. m. of the 7th.

The water continued to rise rapidly at Galveston, and was 8 feet at 3 p. m. of the 8th, notwithstanding there had been up to this time a prevailing offshore north wind of 20 to 40 miles per hour; such winds ordinarily give a tide below low water. After 3 p. m. of the 8th, when the wind shifted to northeast and east the tide rose with phenomenal rapidity, reaching 15 feet at 8 to 9 p. m., a rise of 1.4 feet per hour. The rapid rise during the last five hours is attributed to the effects of the off shore north winds prior to 3 p. m. having retarded the rise in the water as the storm approached, by forcing it

back and banking it toward the storm center, and when the wind changed to northeast and east this water was forced in rapidly with favorable winds. The rise in the storm tide was not noticeable on the coast 50 miles to the left of the line of advance of the hurricane.

The destruction of property by the winds and waves in this hurricane amounted to about $30,000,000 and 6,000 persons were drowned.

July 5–10, 1901.—A storm of small extent and moderate intensity moved through the Yucatan Channel into the Gulf of Mexico on the 7th and reached the Texas coast west of Galveston on the 10th. This disturbance gave a rise in water at Galveston of 4.5 feet at 3:30 a. m. No tide records of this disturbance are available. No damage of consequence resulted.

August 9–15, 1901.—This disturbance first appeared to the north of Cuba on August 9. It moved across southern Florida and into the Gulf of Mexico on the morning of the 11th, continued its course westward until the 90th meridian was reached, when, during the 14th, it recurved and on the morning of the 15th passed northeastward between New Orleans and Port Eads. This disturbance was of small diameter, but of considerable intensity. Its course was unusual.

The barometer at Port Eads fell steadily, commencing about noon on the 12th and was 29.50 at 8 a. m. on the 14th, when the last observation was taken. The wind direction was northwest on the afternoon of the 12th and was northeast during the 13th; on the morning of the 14th it was southeast. The velocity increased steadily after 6 a. m. of the 13th, and was 62 miles per hour at 5 a. m. on the 14th, when the record was lost. The wind and pressure records at New Orleans are shown on Plate II, along with the wind, pressure, and tide records at Port Eads. (We have no automatic tide record for Mobile and Galveston for this storm.) The highest wind velocity, 40 miles per hour at New Orleans, occurred at 11 a. m. on the 15th.

Tide records at Port Eads show the water rising before midnight on the 12th when the center of the storm was about 200 miles distant. The water reached a height of 4.2 feet above mean low water at 11 a. m. on the 14th, the record after that time being lost. The Mississippi River at New Orleans rose from 5.9 feet to 11.4 feet on the morning of the 15th, the water forced up the river by the hurricane winds amounting to 5.5 feet.

At Mobile the water was driven in and was awash of the wharves from 12 noon to 1 p. m. of the 14th. At 10 a. m. of the 15th the water began to come over the wharves, rising at the rate of nearly 1 foot per hour until 3:30 p. m., when it was 5 feet over the wharves and 8.2 feet above mean low tide.

Ten persons were drowned and the damage caused by the storm was $1,000,000.

September 23–27, 1906.—This disturbance passed through the Yucatan Channel on the morning of the 24th,

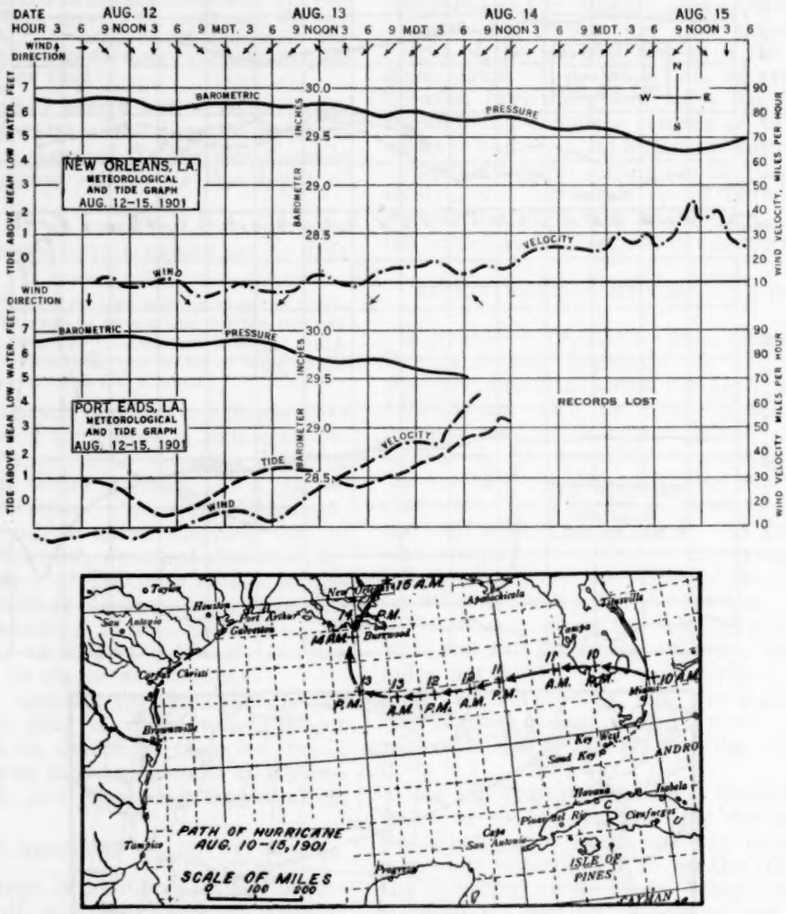


PLATE II.—*I. M. Cline.*

traveled in nearly a straight line, and moved in on the Mississippi coast on the morning of the 27th. The tide records at Port Eads, charted with the wind and pressure records of New Orleans (Port Eads meteorological records being missing) and the Galveston pressure, wind, and tide records during the storm are shown on Plate III. This was a hurricane of large extent and unusual intensity. The tide at Galveston during the passage of this disturbance through the Gulf showed only normal changes. At Port Eads, 50 miles to the left of the line of advance of the center of the storm, the storm tide commenced rising during the afternoon of the 25th, when either Mobile or Pensacola during this hurricane. The United States engineers at Fort Barancas on the bay below Pensacola, give the extreme storm tide at that place, 10.8 feet. At Mobile, the water was 9.9 feet above mean low tide. Thus we have the highest water at Port Eads, 50 miles to the left of the line of advance of the center of the hurricane, 3.8 feet, and at Pensacola, 100 miles to the right, 10.8 feet.

The damage from the hurricane at Pensacola was $2,120,000, and in the vicinity of Mobile, $1,850,000. The total known deaths at Pensacola were 32, and in the vicinity of Mobile 31 persons lost their lives.

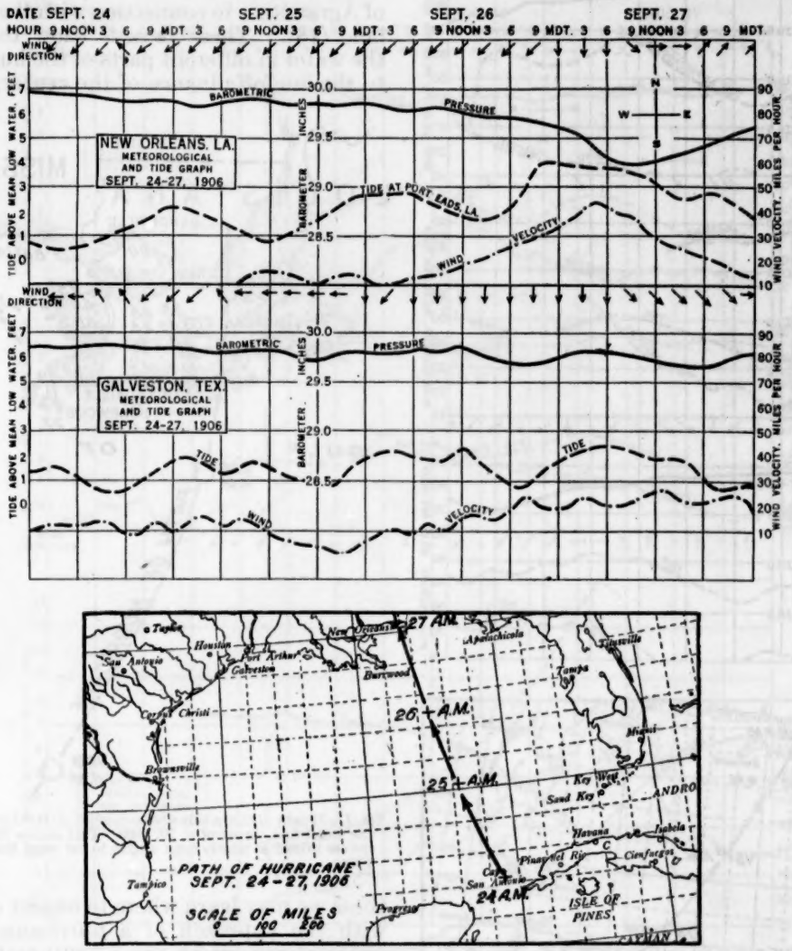


PLATE III.—*I. M. Cline.*

the hurricane was 250 miles distant in space and 28 hours in time. The rise in water shown at Port Eads on the afternoon of the 25th must have started from the southeast Gulf during the afternoon of the 24th and traveled, during 20 hours, a distance of more than 500 miles, at the rate of about 25 miles per hour. The cyclonic area advanced at the rate of about 10 miles per hour. The highest tide at Port Eads was 3.8 feet at midnight of the 26th. There was 3-foot rise in the river at New Orleans on the morning of the 27th as a result of the hurricane. Mobile and Pensacola were situated in the eastern segment of the cyclonic area, where they experienced the severest part of the hurricane. Both places reported the severest hurricane in their history. Unfortunately, we have no automatic tide records for

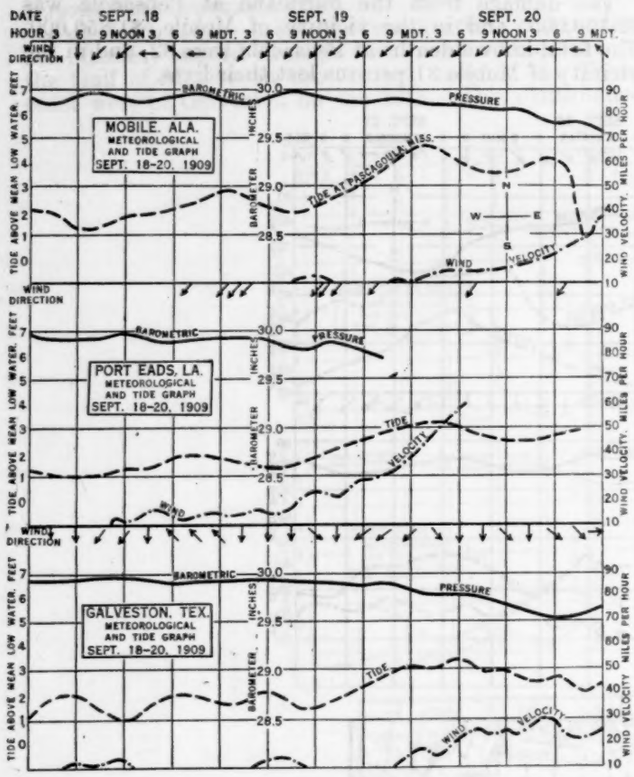
July 18–21, 1909.—This disturbance moved from the Caribbean Sea through the Yucatan Channel on the 18th and moved inland on the Texas coast with its center near Velasco. The cyclonic area was about 100 miles in diameter and no hurricane winds attended it. High waves, swells, and tides prevailed as far to the right of the center as Galveston. We have no tide records for this storm.

The damage to property amounted to $100,000 and 4 lives were lost.

September 12–21, 1909.—This was a storm of great intensity and of large extent, its effects being distinctly felt from east of Pensacola, Fla., to the west of Galveston, Tex. The disturbance passed through the Yucatan Channel during September 17 and moved inland on the

Louisiana coast, its center a little distance to the right of the mouth of the Atchafalaya River, September 20. This disturbance advanced at the rate of about 8 miles per hour.

The meteorological and tide records at Mobile, Ala. (tide records from Pascagoula, Miss.), Port Eads, La., and Galveston, Tex., are shown on Plate IV. The storm tide began rising at Pascagoula, Miss., and Port Eads, La.,



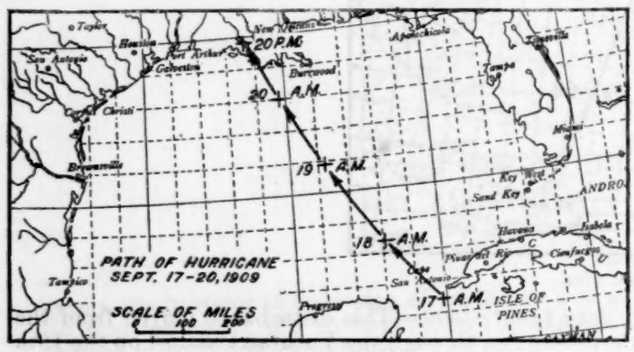


PLATE IV.—*I. M. Cline.*

about the same time on the afternoon of the 18th, when the center of the disturbance was nearly 400 miles distant in space and 40 hours in time. The rise which commenced at Port Eads and Pascagoula at 8 p. m. of the 18th had started from the southeast Gulf about 18 hours previously and had traveled about 500 miles at the rate of 28 miles per hour. By noon of the 19th there had been a rise at Pascagoula of 1.1 feet, and at Port Eads of 0.8 foot, and by midnight of the 19th the water had risen 2.4 feet at Pascagoula and 2 feet at Port Eads. No material changes in the tide other than the regular change were shown at Galveston until the night of the 19th. The storm tide from the forenoon of the 18th to the forenoon of the 20th at Pascagoula, Miss., was about 2.8 feet, and at Port Eads, La., 2.2 feet, and at Galveston, Tex., 1 foot. The rise in the tide at Galveston all occurred during the night of the 19th-20th.

The wharves at Mobile were overflowed and the water was within half a block of Royal Street, the height of the water at that place being 8.7 feet.

The height of the water above mean Gulf level over the Louisiana coast region in the hurricane of September 20, 1909, has been determined by engineers of the Department of Agriculture in connection with the reclamation of marsh land (18). These records show the greatest height of the water in different parts of the hurricane with reference to the line of advance of the center, and from a study of

FIG. 1.—Height of storm tide above mean Gulf level in right and left hand segments of the hurricane, September 20, 1909. This shows the area overflowed when storm moves inland at nearly right angles to the coast line.—*A. M. Shaw* (18) and *I. M. Cline.*

these we may learn where to expect dangerous storm tides with the approach of a hurricane. The height of the water at several places in southeastern Louisiana during the hurricane of September 20, 1909, is shown in figure 1. Seven parishes were flooded, the height of the water being 6 to 10 feet over the greater portion of the area. The actual height of the water over the land in the right-hand segment of the cyclonic area resulted from the accumulation of water forced forward by the winds and checked in speed by the marsh lands, swamp forests, and levees. This is distinctly shown by the increased depth of 2 to 4 feet of water 30 to 50 miles inland from Burrwood and Port Eads. The depths of 7 to 10 feet occurred at points where the greatest resistance to the advancement of the water, forced forward by the winds, was encountered. To the left of the line of advance of the center of the hurricane, the water did not get high enough at any point to attract attention and at Morgan City, La., near the center

and in the left-hand segment of the cyclonic area, the water was 0.1 of a foot below mean Gulf level, while 75 miles to the right of the center the water was 5 to 7 feet above.

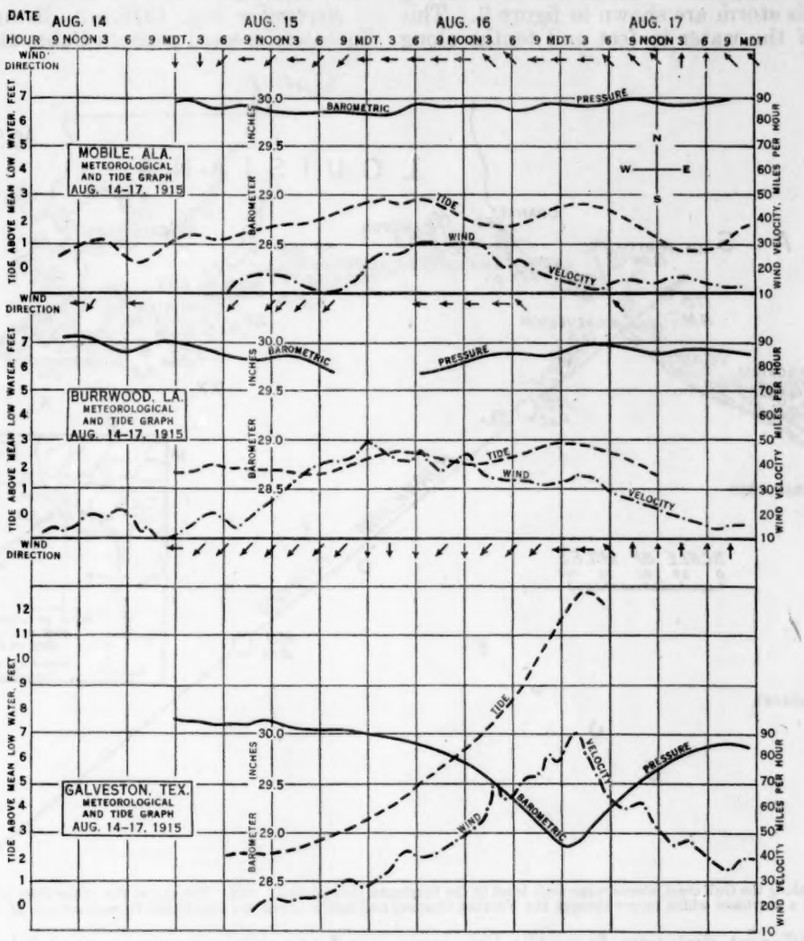
The damage to property by this storm amounted to $6,400,000, and 353 lives were lost.

October 13–18, 1910.—This disturbance moved into the Florida Straits on the 14th, moved toward the northwest during the 15th, southward during the 16th, and then eastward to the Florida Straits by the morning of the 17th, after which it moved northward over Florida during the 18th. Barograph records of the French S. S. *Texas* from the 13th to the 17th confirm this movement.* We have no tide records for this disturbance. The official in charge, Weather Bureau Office, Tampa, Fla., reports the tide 6.6 feet below mean low water on the morning of the 18th, the lowest water of record, the cyclonic area at that time was moving northward with its center to the right of Tampa. After the passage of the center of the storm and its recurve northward, the water rose 10.1 feet, to 3.5 feet above mean low tide.

August 13–17, 1915.—This hurricane moved across the western end of Cuba into the Gulf of Mexico during the forenoon of the 14th, traveled in a direct line and passed inland on the Texas coast a short distance to the left of Galveston on the morning of the 17th. The disturbance advanced with a speed of about 12 miles per hour.

The wind, pressure and tides at Mobile, Ala. (tide at Fort Morgan), Burrwood, La., and Galveston, Tex., are shown on Plate V. The storm tide began rising slowly at Galveston, Burrwood, and Fort Morgan during the forenoon of the 15th, just 24 hours after the disturbance had moved into the Gulf of Mexico. These rises in the water over a coast line more than 500 miles long all on the right of the line of advance of the hurricane resulted from waves started out from the region covered by the hurricane in the southeast Gulf during the 14th. The distance of the center of the storm at that time from Fort Morgan and Burrwood was 450 miles and from Galveston, 700 miles. This would indicate that waves and swells were carried forward in the front of the right-hand segment in the line of advance of the hurricane at a velocity of 40 to 50 miles per hour and those going toward shore farther to the right of the line of advance traveled with a little less than half that speed. The highest water at Fort Morgan, 2.8 feet, was recorded at 6 a. m. on the 16th and showed a rise of 1.8 feet in 24 hours. At Burrwood, 2.6 feet was recorded at 1 a. m. of the 16th, a rise of 1 foot in 24 hours. The tide did not rise after that to any extent, at either of these places, but high water continued at Fort Morgn and Burrwood until the storm moved inland; the regular tides were not obscured.

At Galveston the tide continued to rise and was 4.1 feet at 6 :30 a. m. on the 16th, a storm tide of about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WIND DIRECTION
TIDE ABOVE MEAN LOW WATER, FEET
INCHES BAROMETER
WIND VELOCITY, MILES PER HOUR
BAROMETRIC PRESSURE
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MOBILE, ALA. METEOROLOGICAL AND TIDE GRAPH AUG. 14-17, 1915
BURRWOOD, LA. METEOROLOGICAL AND TIDE GRAPH AUG. 14-17, 1915
GALVESTON, TEX. METEOROLOGICAL AND TIDE GRAPH AUG. 14-17, 1915

PLATE V.—For path and movement of hurricane, August 14-17, 1915, see figure 2.—*I. M. Cline.*

* It is hoped at a later date to publish a full discussion of all reports of this remarkable storm.—EDITOR.

3.1 feet in 24 hours. The center of the disturbance at this time was nearly 300 miles from Galveston and 21 hours distant in time. The rise in the water in front of the storm at this hour at Galveston was nearly twice the rise of 1.8 feet at Fort Morgan, 300 miles to the right of the line of advance of the hurricane, and was three times greater than the rise at Burrwood. The water continued to rise at Galveston until about 3 a. m. of the 17th, when it was 12 feet. The tide changed very little at Fort Morgan and Burrwood after 3 a. m. of the 16th and commencing at 3 a. m. of the 17th, fell to about normal on the afternoon of that date.

The heights of the water above mean Gulf level along the coast during this storm are shown in figure 2. This shows the height of the water in feet and tenths along the Gulf coast at different distances from the line over which the center of the hurricane advanced.

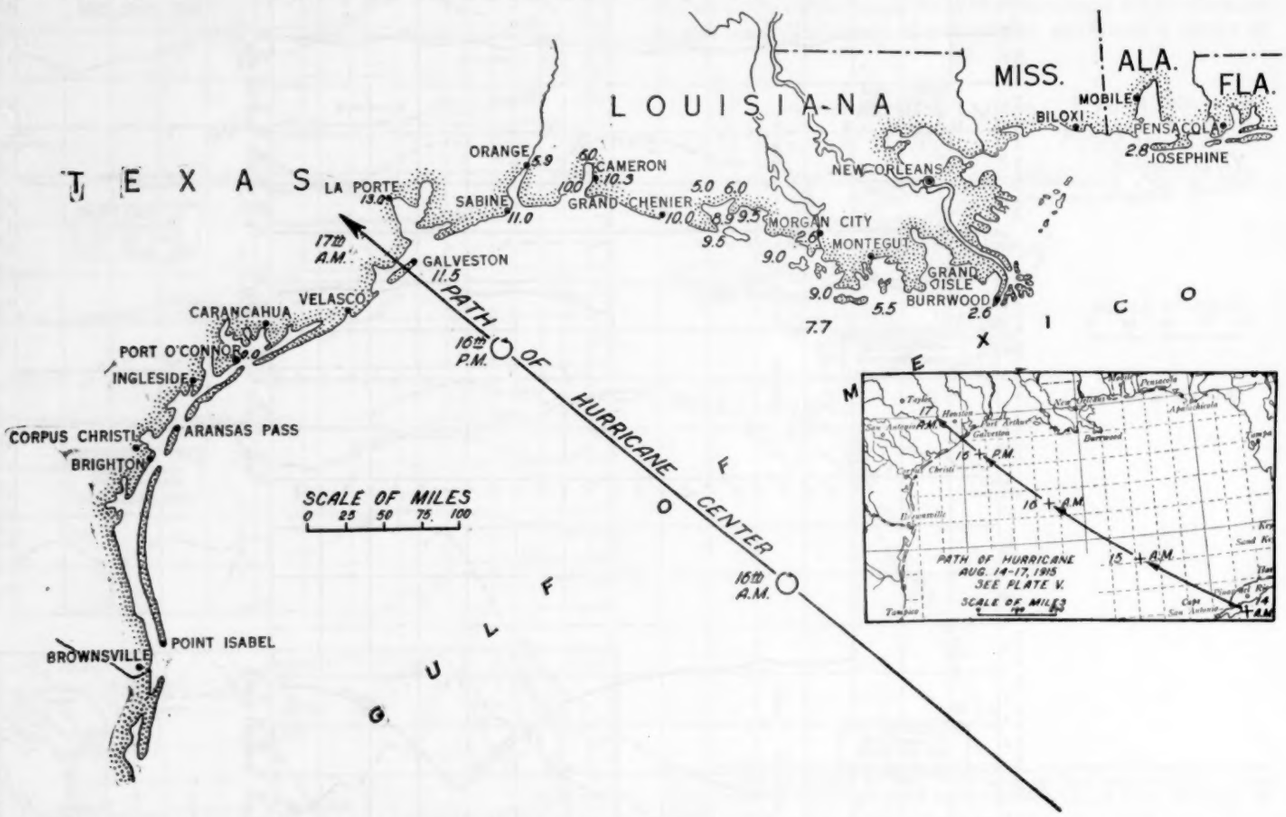


FIG. 2.—Height of storm tides along the Gulf coast, above mean Gulf level in the hurricane, August 16-17, 1915. This shows the storm tides at various distances from the center of a hurricane which moves through the Yucatan Channel and thence across the Gulf to the Texas coast.—*I. M. Cline.*

During the passage of this hurricane, the action of waves and currents in moving objects in the open Gulf was brought out by the movement of light and whistling buoys that were within its range. Trinity Shoals gas and whistling buoy, weighing 21,000 pounds, anchored in 42 feet of water, with 6,500 pound sinker and 252 feet of anchor chain weighing 3,520 pounds, was carried 8 to 10 miles westward of its proper location in latitude 29° 07′ N. and longitude 92° 15′ W. The shape and exposure of the buoy are shown in figure 3. The location of this buoy was 100 miles to the right of the line of advance of the center of the storm.

Galveston Bar gas and whistling buoy, same as shown, anchored at the end of Galveston Jetties in 36 feet of water was carried 4½ to 5 miles in a southwesterly direction from its proper location. This buoy was about 20 miles from the center of the storm.

A buoy of the same class, with the same moorings in 42 feet of water, located on Heald Bank, 28 miles off the entrance to Galveston Bay, was not moved from its proper position, although its lights were extinguished. The Heald Bank buoy was a little to the left of the line of advance of the center of the hurricane. From the action of the water on these buoys we can get some information concerning the effects of currents and waves attending hurricanes.

The property damage in this storm was about $21,000,000, and 275 lives were lost.

September 2–4, 1915.—A disturbance of considerable intensity crossed western Cuba, moved into the east Gulf and recurving slowly, moved inland near the mouth of the Apalachicola River during the early morning hours of the 4th. Pressure, wind and tide graphs for Mobile (tide, Fort Morgan), Ala., and Burrwood, La., are shown in Plate VI. These stations were located, Fort Morgan, 100 miles, and Burrwood, 200 miles to the left of the line of advance of the center of the storm. The tides at these stations were not influenced in any manner by the disturbance and there was no high tide at Pensacola. Along the Florida coast, to the right of the line of advance high water prevailed generally. At St. Petersburg, Fla., water was 4.9 feet above any previous high water.

September 22–30, 1915.—This was one of the most intense hurricanes in the history of the Gulf coast. The cyclonic area moved through the Yucatan Channel during the night of the 27th, and traveling northwestward moved inland on the Louisiana coast to the left of and

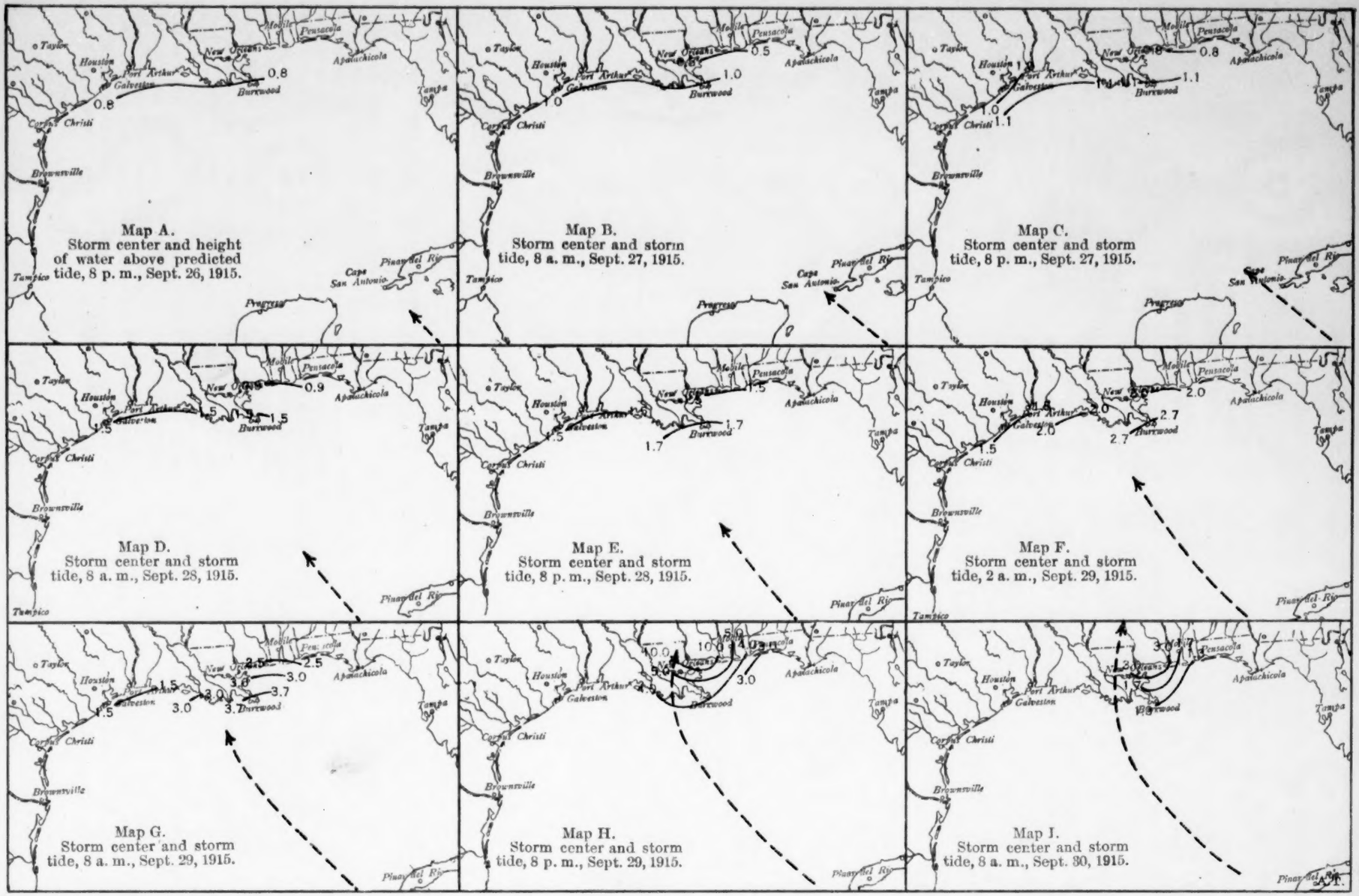

Map A.
Storm center and height of water above predicted tide, 8 p. m., Sept. 26, 1915.
Map B.
Storm center and storm tide, 8 a. m., Sept. 27, 1915.
Map C.
Storm center and storm tide, 8 p. m., Sept. 27, 1915.
Map D.
Storm center and storm tide, 8 a. m., Sept. 28, 1915.
Map E.
Storm center and storm tide, 8 p. m., Sept. 28, 1915.
Map F.
Storm center and storm tide, 2 a. m., Sept. 29, 1915.
Map G.
Storm center and storm tide, 8 a. m., Sept. 29, 1915.
Map H.
Storm center and storm tide, 8 p. m., Sept. 29, 1915.
Map I.
Storm center and storm tide, 8 a. m., Sept. 30, 1915.
Taylor
Houston
Port Arthur
Galveston
Burrwood
Mobile
Pensacola
Apalachicola
Tampa
Corpus Christi
Brownsville
Tampico
Progreso
Cape San Antonio
Pinar del Rio

FIG. 4.—Storm tides on the Gulf coast, September 26–30, 1915. Maps A, B, C, D, E, F, G, H, I. The point of the arrow indicates the position of the center of the hurricane. The figures at the ends of the lines drawn near the shore show the rises of the storm tide on the coast as the storm advanced; that is, the height of the water above the predicted tide at that hour. This is for a storm that recurved slowly.

near Grand Isle, La., during the 29th. This disturbance recurved slowly after crossing latitude 27° N. and moved slowly northward.

The pressure, wind and tides at Mobile (tide records Fort Morgan), Ala., Burrwood, La., and Galveston, Tex., are shown in Plate VII. The tide was about 0.8 of a foot above the predicted tide at 8 p. m. on the 26th. At 8 a. m. on the 27th the water had commenced rising at Fort Morgan and was 1 foot above the predicted tide on the Gulf coast from Burrwood to Galveston; at 8 p. m. the excess was 1.1 feet. At 8 a. m. of the 28th,

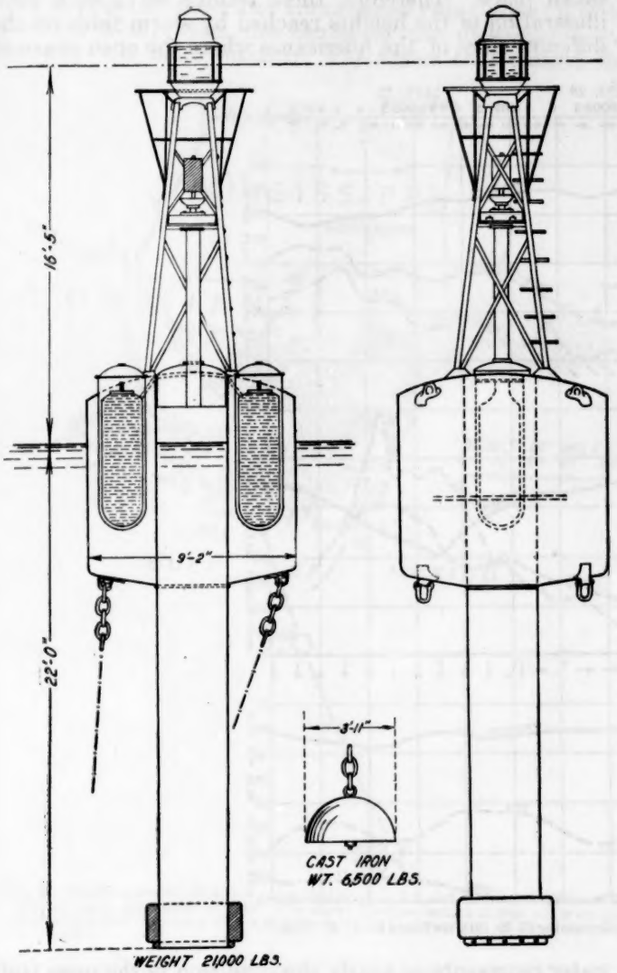
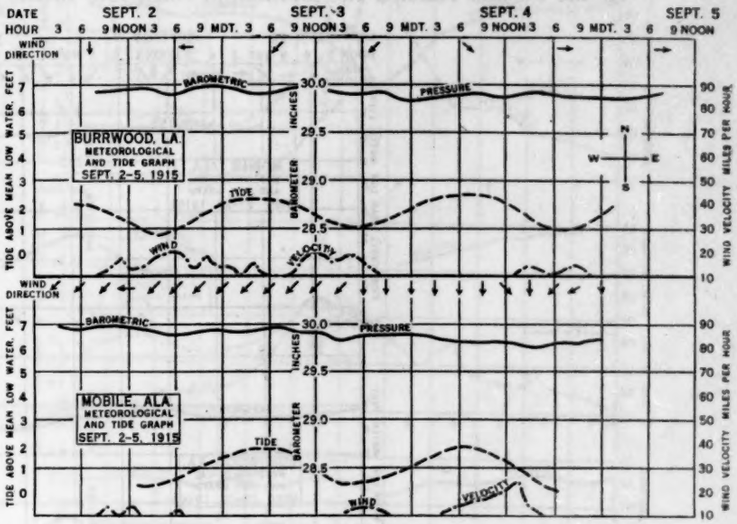


FIG. 3.—Design of gas and whistling buoy anchored at Trinity Shoals, Louisiana coast; Galveston Bar, off jetties and Heald Bank, Tex. Trinity Shoals and Heald Bank buoys are anchored in 43 feet and Galveston Bar in 36 feet of water.

there was 1.5 feet of water in excess of the predicted tide at Burrwood and Galveston and 0.8 foot at Fort Morgan. At 8 p. m. of the 28th, when the storm was about 250 miles distant, there was a storm tide of 1.7 feet at Burrwood and 1.5 feet at Fort Morgan. When the storm began recurving to the right, the water ceased rising at Galveston, and no storm tide was recorded there after 8 a. m. of the 28th. At 2 a. m. of the 29th, the tide had continued rising on the middle Gulf coast and showed 2.7 feet at Burrwood and 2 feet at Fort Morgan. At 8 a. m. of the 29th, the storm tide had risen to 3.7 feet at Burrwood and 2.5 feet at Fort Morgan. The rise of the storm tide is shown in figure 4.

The storm waters were carried over southeastern Louisiana and the depth was more than 12 feet on the shore of Lake Pontchartrain and 10 to 11 feet on the Louisiana and Mississippi coasts. High water prevailed to the right of the center of the hurricane to the eastward of Pensacola, where the water was 4 feet high, and at Mobile the storm water was banked up 7.2 feet. The distribution of the storm waters along the middle Gulf coast in the different parts of the hurricane are shown in figure 5. The height of the water in the open Gulf, as nearly as we can expect to get records, was 4.6 feet, 45 miles to the left of the center of the storm at a lighthouse about 10 miles out in the Gulf from Raccoon



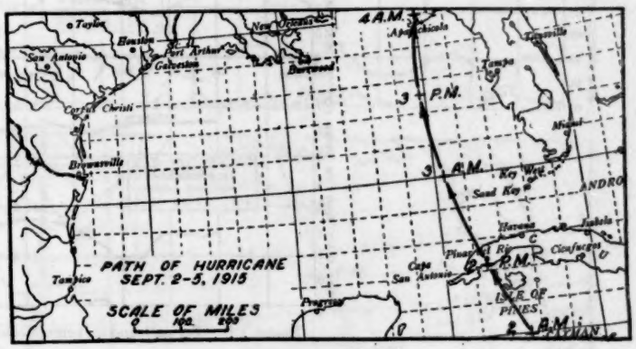


PLATE VI.—*I. M. Cline.*

Point; 8.4 feet at Timbalier Light, a few miles to the right of the center, which is 10 miles from land; and 5.8 feet at Burrwood, about 60 miles to the right of the center. No water was carried inland to the left of the line of advance of the center of the hurricane, and at Morgan City, 15 miles from the Gulf, the tide was 0.4 of a foot below mean Gulf level. At Pensacola, 175 miles to the right of the center, the tide was 4 feet; at Mobile, 150 miles, it was 7.2 feet; at Gulfport, Miss., 80 miles, it was 9.6 feet; at Bay St. Louis, 65 miles, it was 11.8 feet.

The center of the storm passed between Lake Pontchartrain and Lake Maurepas. In Lake Pontchartrain, to the right of, but nearly in the center of the hurricane, the water was 13 feet at Frenier, due to the wind forcing the water up against a dense growth of timber in that

locality. A few miles further along the line of advance of the center of the storm, near the connection between Lake Pontchartrain and Lake Maurepas, where there was open space, the height of the water was 6 feet. At Frenier we find that the force of the wind, with about 25 miles open waterway, banked the water 13 feet against an obstruction of only a few miles extent, 7 feet higher than on either side.

The damage resulting from this hurricane is estimated at $13,000,000, and 275 persons were drowned.

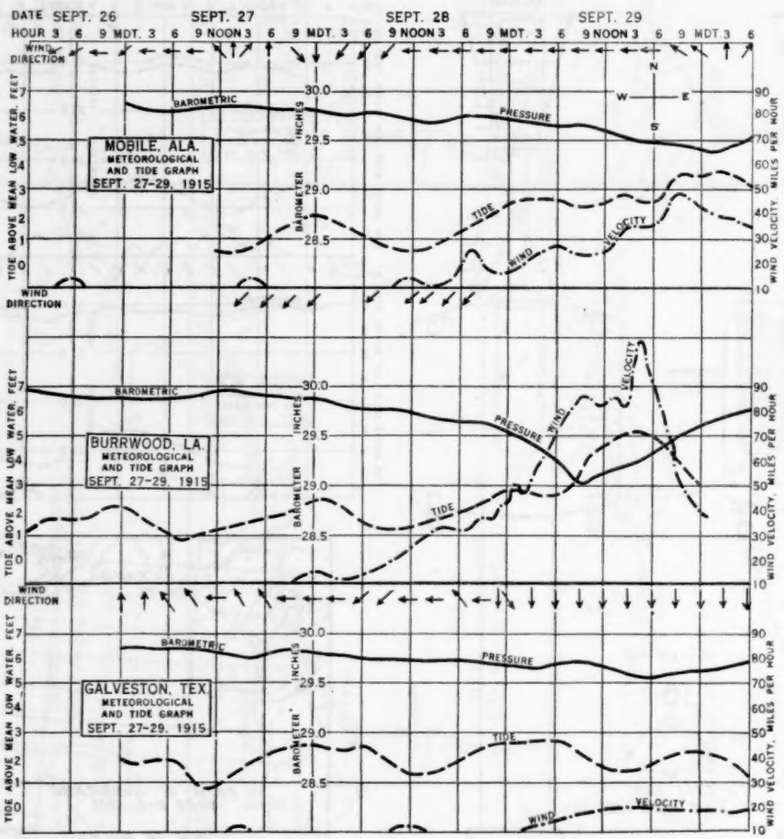
July 1–6, 1916.—This disturbance made its appearance in the Caribbean Sea on the afternoon of the 1st, moved almost in a straight line through the Yucatan Channel on the 3d and reached the Mississippi coast late in the afternoon of the 5th. The storm covered a considerable area and was of geat intensity.

The wind, pressure, and tides at Mobile (tide records, Fort Morgan), Ala., Burrwood, La., and Galveston, Tex., are shown in Plate VIII. The tide at Mobile and Burrwood was rising at noon of the 4th when the disturbance was centered 400 miles distant in space and 26 hours in time. This rise of water had traveled from the Yucatan Channel a distance of 500 miles in 18 hours in the front and to the right of the line of advance of the center of the cyclonic area. At midnight of the 4th the water had risen 1 foot at Burrwood and 1.4 feet at Fort Morgan. At 8 a. m. on the 5th the storm tide was 2.8 feet at Port Eads and Burrwood and 3 feet at Fort Morgan. The highest water at Fort Morgan was 5.3 feet and occurred at 1 p. m. of the 5th; at Burrwood the highest water was 3.8 feet at 10 a. m. of the 5th. Burrwood was about 25 miles to the left and Fort Morgan about 75 miles to the right of the line of advance of the center. The distance traveled by the center of the disturbance after passing Burrwood before coming in a line with Fort Morgan was 50 miles.

The difference in time between the passage of the crest of high water at Burrwood and Fort Morgan, 3 hours, would indicate speed of about 15 miles per hour, which is the same as the progressive speed of the cyclonic area. The location of these stations is such that no great banking up of water by physical obstruction was likely to have taken place. Therefore, these records serve as a good illustration of the heights reached by storm tides on the different sides of the hurricanes where the open space of water represents as nearly the condition in the open Gulf as we can expect to find. Fort Morgan was three times farther than Port Eads from the center. As the shore was approached the water banked up much higher, this being due to physical obstructions. The height of the water at Mobile was 11.6 feet, which is 6.3 feet above the actual height reached by the water at Fort Morgan. High water did not occur as far west as Biloxi and Pass Christian. The damage at Mobile and on the Alabama coast amounted to $2,500,000, and 12 persons were drowned. The height of the water at Pensacola, Fla., was 5 feet.

The damage at Pensacola amounted to $1,000,000. The storm did not influence the tide in any manner at Galveston, Tex.

August 12–19, 1916.—This disturbance passed through the Yucatan Channel into the Gulf of Mexico during the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WIND DIRECTION
BAROMETRIC PRESSURE
MOBILE, ALA. METEOROLOGICAL AND TIDE GRAPH SEPT. 27-29, 1915
TIDE
WIND VELOCITY
BURRWOOD, LA. METEOROLOGICAL AND TIDE GRAPH SEPT. 27-29, 1915
GALVESTON, TEX. METEOROLOGICAL AND TIDE GRAPH SEPT. 27-29, 1915
TIDE ABOVE MEAN LOW WATER, FEET
BAROMETER, INCHES
WIND VELOCITY, MILES PER HOUR
N
W
E
S

PLATE VII.—For path and movement of hurricane, September 27-29, 1915, see figure 4.—*I. M. Cline.*

night of the 16th, advanced northwesterly in nearly a straight line, and moved inland on the Texas coast midway bewteen Corpus Christi and Brownsville during the afternoon of the 18th.

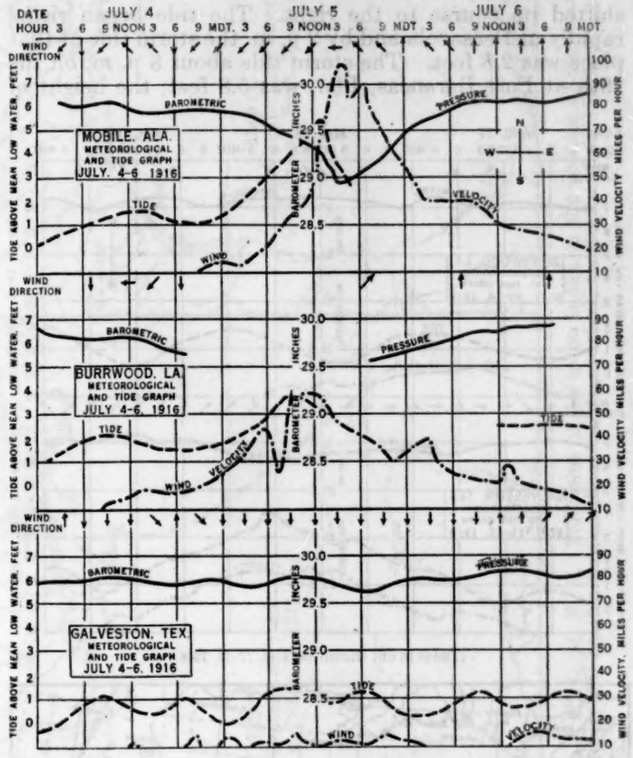
We have no tide records in the vicinity of the center of this hurricane, but wind, pressure, and tide records at Burrwood, La., 400 miles to the right, and Galveston, Tex., 250 miles to the right of the line of advance of the center of the hurricane, are shown in Plate IX. No appreciable influence was shown on the tide at Burrwood. At Galveston, 250 miles to the right of the line of advance of the center, the water commenced rising about 6 p. m. of the 17th, when the center of the disturbance was nearly 400 miles distant. The water that caused this

FIG. 5.—Height of storm tide above mean Gulf level, in left and right hand segments of the hurricane, September 29, 1915. This shows the distribution of high water on the middle and east Gulf coast with a slowly recurving hurricane.—*C. W. Okey* (18) and *I. M. Cline.*

rise must have started on its journey toward the Texas coast when the storm was passing through the Yucatan Channel and had traveled a distance of nearly 800 miles, showing a speed of about 40 miles per hour. The cyclonic area advanced at the rate of about 18 miles per hour. The water at Galveston rose steadily from 6 p. m. on the 17th until 6 p. m. of the 18th, when the height of the water was 4 feet, about 3 feet being storm tide. Galveston, at the time of the occurrence of the highest water, was 200 miles from the center, and a line drawn through Galveston and the center of the storm at that time crossed the line of advance at right angles. The advance of the hurricane was more prominently shown in the rise of the water at Galveston than in the pressure or wind changes.

The damage caused by this hurricane was estimated at $1,800,000, and 15 persons were killed or drowned.

September 21–29, 1917.—This disturbance moved through the Yucatan Channel into the Gulf of Mexico during the night of the 25th and advanced in a direction a little west of north toward the mouth of the Mississippi River. When within about 50 miles of Port Eads the storm began recurving to the right, and the center, passing about 50 miles to the right of Port Eads, La., moved inland to the right of Pensacola, Fla.



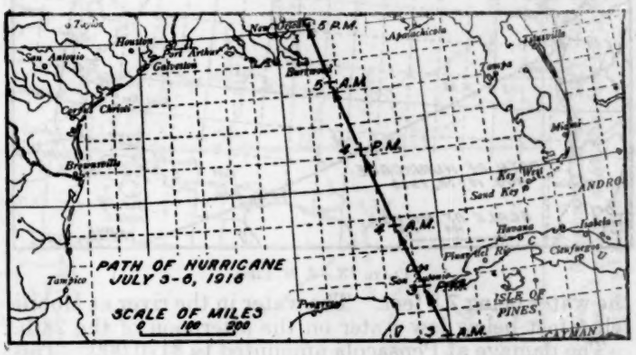
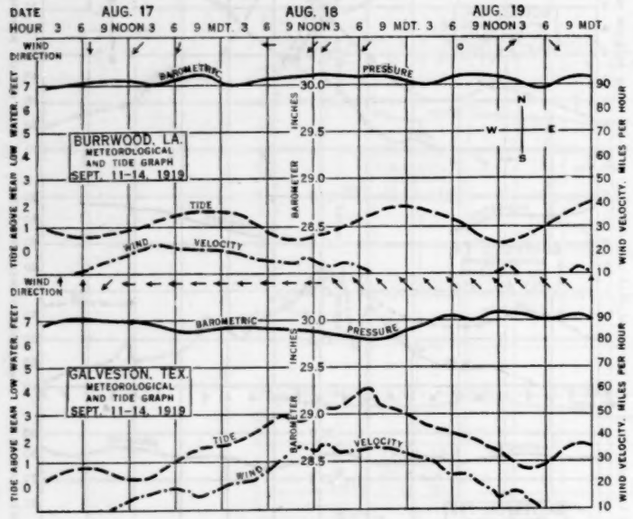


PLATE VIII.—*I. M. Cline.*

The pressure, wind, and tides for Pensacola, Fla. (the tides are drawn from the observations made by the observer of the Weather Bureau except the highest stage, which was obtained from the United States Engineers), Burrwood, La. (tide Port Eads), and Galveston, Tex., are shown in Plate X.

The changes in the height of the water with the advance of the hurricane are shown in figure 6. The changes in the tide in a recurving hurricane are shown in this case. The tide commenced rising at both Pensacola and Port Eads during the night of the 26th and was 0.6 to 0.7 of a

foot above the predicted tide at 8 a. m. of the 27th, when the disturbance was centered about 200 miles from Port Eads and 300 miles from Pensacola. At 8 p. m. of the 27th there was 1.0 foot of storm tide at both Pensacola and Port Eads. On the morning of the 28th the line of advance of the center, if continued, would have carried the center of the storm over Port Eads, which place had a storm tide of 2.7 feet, and Pensacola only 1.1 feet. At 10 a. m. reports from Pilottown showed the storm had shifted its course to the right. The tide began rising rapidly at Pensacola and by 2 p. m. the storm tide at that place was 2.8 feet. The storm tide about 8 p. m. on the 28th at Fort Barancas, Fla., was 5.8 feet, the height of



(Dates in cut should be Aug. 17–19, 1916.)

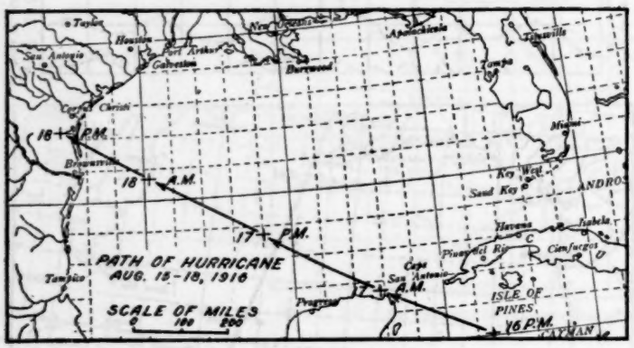


PLATE IX.—*I. M. Cline.*

the water being 7.8 feet. The water in the river at Mobile fell 5 feet below low water on the afternoon of the 28th.

The damage at Pensacola amounted to $170,000. This place was near the center of the storm, but being to the left of the line of advance, suffered very little damage, notwithstanding the intensity of the hurricane.

August 1–6, 1918.—This disturbance moved through the Yucatan Channel into the Gulf of Mexico during the night of the 4th, traveled in a northwesterly direction and passed inland over Lake Charles, La., during the 6th. The hurricane was small but of marked intensity. We have no tide records for this storm, but at Morgan City, 150 miles to the right of the line of advance of the center of the storm the tide rose 3 feet, and 28 miles west of the center, at Johnsons Bayou, there was a tide of 2.8 feet.

The damage from the hurricane amounted to $5,000,000 and 34 deaths resulted.

September 6–14, 1919.—This disturbance passed through the Florida Straits during the night of the 9th, moved very slowly during the 10th, 11th, and 12th, with its line of advance pointing toward the Louisiana coast west of the Atchafalaya River. On the 13th the disturbance changed its course to the westward, moved rapidly in almost a straight course, and passed inland with its center a short distance to the left of Corpus Christi, Tex., during the afternoon of the 14th.

The pressure, wind, and tides at Burrwood, La., and Galveston, Tex., are shown on Plate XI. The tide record at Galveston was incomplete after 12 noon of the 13th. The highest point reached by the water has been obtained from the United States Engineers and other records from tide heights telegraphed by the observer at Galveston with observations, and these data have been supplemented by other reports. We have thus been able to complete the tidegraph with a fair degree of accuracy. The long stretch of open water, more than 1,000 miles, traversed by this hurricane after entering the Gulf of Mexico, furnishes a splendid opportunity to study the changes in the stages of the water along the coast both in front and along the line of advance of the center of the hurricane.

The storm tides and their changes with the advance of the hurricane from the morning of the 11th until the afternoon of the 14th, when the hurricane moved inland, are shown in figure 7. There was a rise of 0.3 foot above the predicted tide at Burrwood, La., at 8 a. m. of the 11th, when the center of the storm was 400 miles distant. At 8 p. m. of the 11th the rise of 0.3 foot had reached Galveston, traveling from the longitude of Burrwood, about 500 miles, in 12 hours, nearly 40 miles per hour, and the storm tide at Burrwood at this time was 1.1 feet. Galveston was at this time 600 miles distant from the center of the hurricane and Burrwood about 350 miles distant. By 8 a. m. of the 12th the storm tide was 1.7 feet at Burrwood and 0.7 of a foot at Galveston; and at 8 p. m. the height of the water in excess of the predicted tide was 1.9 feet at Burrwood and 1.6 feet at Galveston.

On the morning of the 13th the hurricane tide was 2.6 feet at Galveston, 300 miles in front of the center, and 2.4 feet at Burrwood, about 200 miles to the right of the line of advance of the center. No increase in the height of the water took place at Burrwood during the 13th, but at Galveston the storm tide at 8 p. m. was 3.6 feet, a gain of 1 foot in 12 hours; at this hour the water had commenced rising slowly at Aransas Pass, Tex. At 3 a. m. on the 14th the storm tide was 7.6 feet at Galveston, and 4 feet at Aransas Pass. At 8 a. m. of the 14th the height of the water had not changed at Galveston, but had risen 2 feet at Aransas Pass, during the preceding five hours and stood 6 feet. When the storm moved inland, about 3 p. m. on the 14th, there was a storm tide of 11.1 feet at Aransas Pass. The water, driven before the wind with the passage of the hurricane inland, banked up in places to depths of 12 to 16 feet.

This storm furnishes a good example for the study of the changes in the depth of the water along the coast in hurricanes which are moving coastwise. These heights are represented in figure 8. The rise of the storm tide in bays and estuaries to the right of the line of advance of the hurricane lags behind the rise on the coast. At Morgan City the highest water, 7 feet, occurred at 4 a. m. on the 14th, six hours after it had occurred on the near-by coast. At La Porte, Tex., near the upper end of Galveston Bay, the highest water, 8.5 feet, was at 1 p. m.

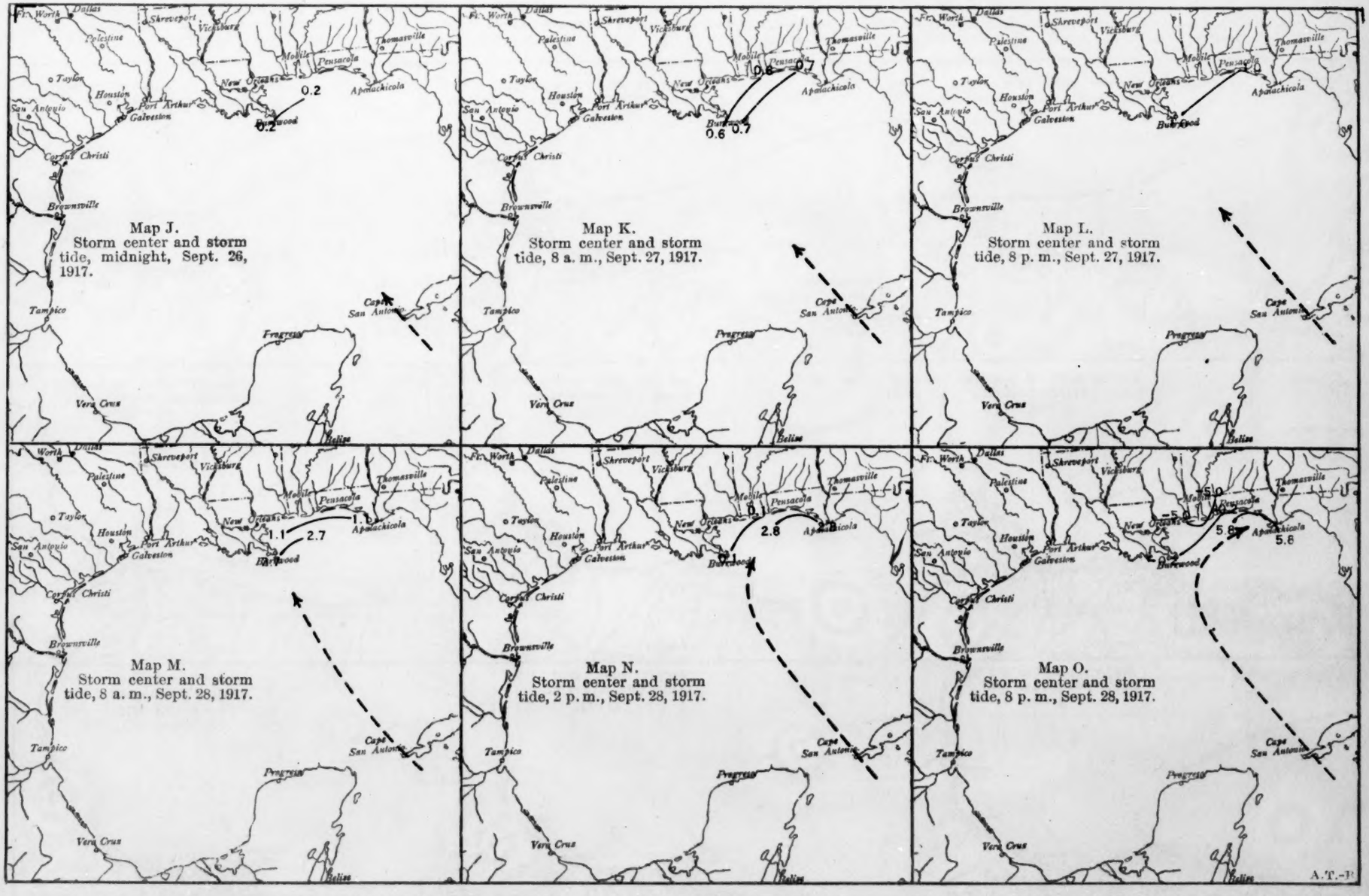


FIG. 6.—Storm tides on the Gulf coast, September 26–28, 1917. Maps J, K, L, M, N, O. The point of the arrow indicates the position of the center of the hurricane. The figures at the ends of the lines drawn near the shore show the rises of the storm tide on the coast as the storm approached; that is, the height of the water above the predicted tide at that hour. This is for a storm that recurved rapidly.

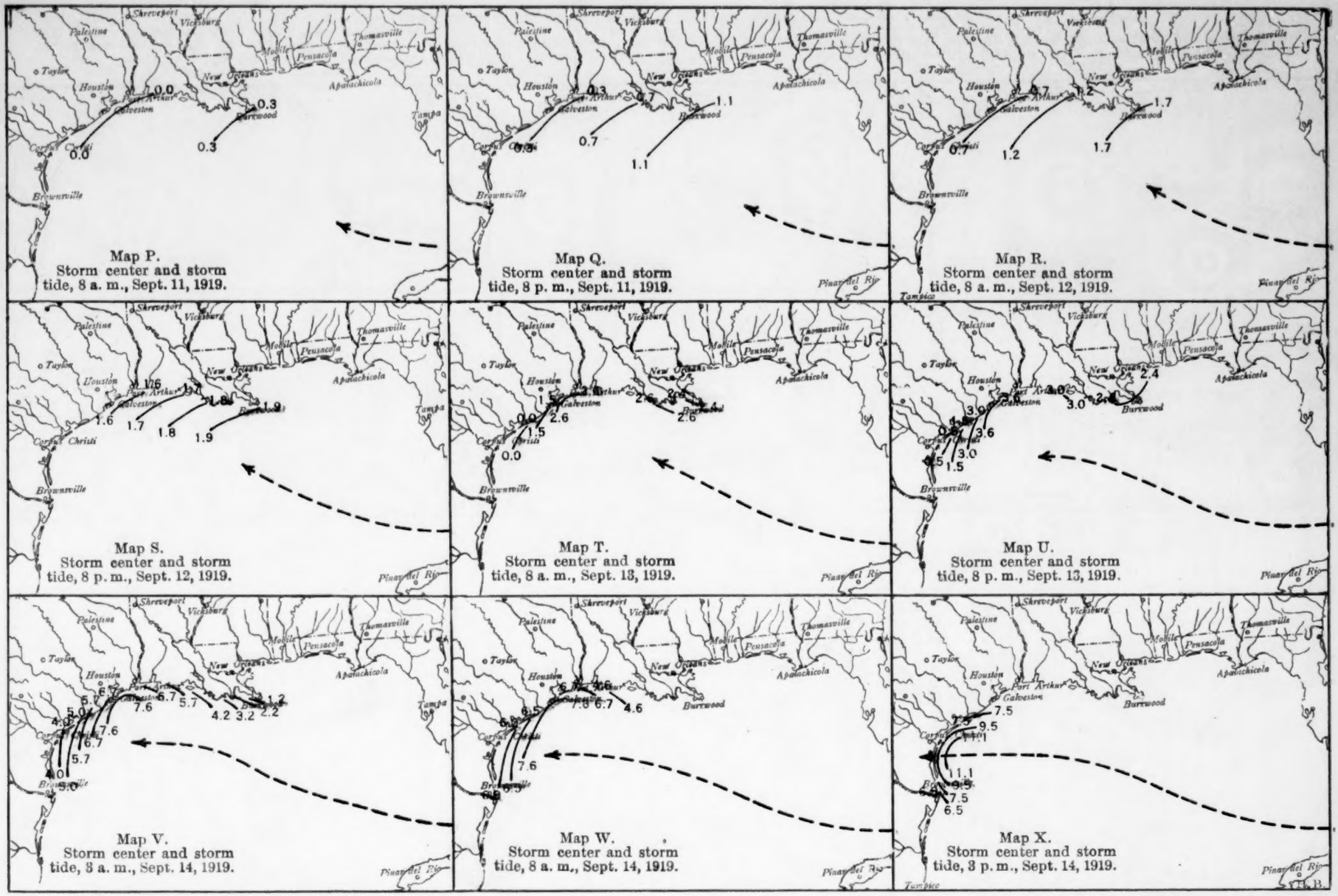


FIG. 7.—Storm tides on the Gulf coast, September 11-14, 1919. **Maps** P, Q, R, S, T, U, V, W, X. The point of the arrow indicates the position of the center of the hurricane. The figures at the ends of the lines drawn near the shore show the rises of the storm tide on the coast as the storm approached; that is, the height of the water above the predicted tide at that hour. This is for a storm that moved coastwise.

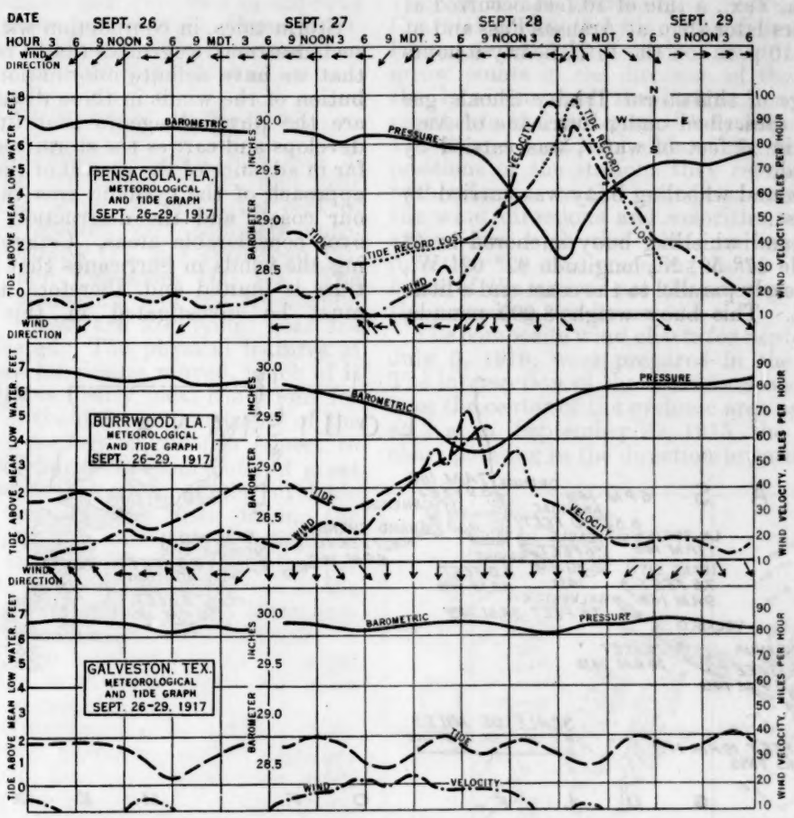


PLATE X.—For path and movement of hurricane, September 26-28, 1917, see figure 6.—*I. M. Cline.*

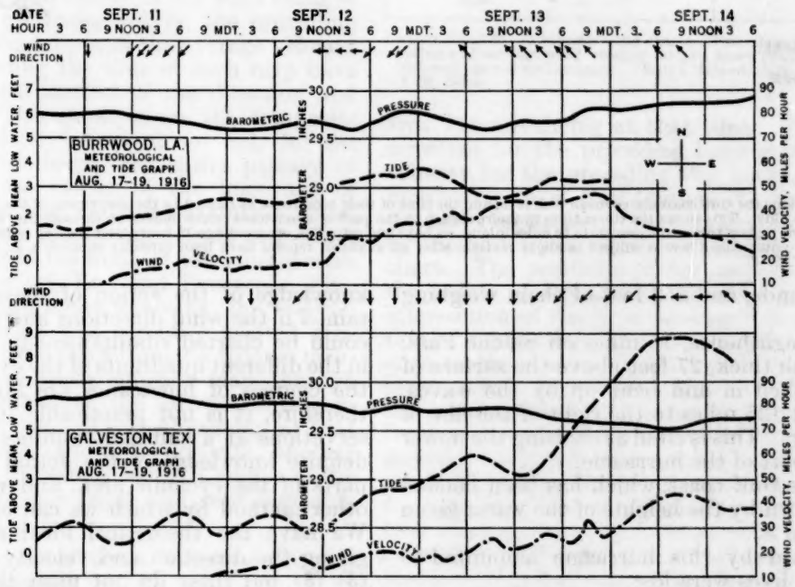


PLATE XI.—For path and movement of hurricane, September 11-14, 1919, see figure 7. (Dates in cut should be Sept. 11-14, 1919.)—*I. M. Cline.*

on the 14th, about 12 hours after it had reached Galveston. At Carancahua, Tex., a tide of 10 feet occurred at 5 p. m., about 2 hours later than at Aransas Pass and at Ingleside, 12 feet at 10 p. m. on the 14th, nearly 9 hours after Aransas Pass.

During the passage of this storm Trinity Shoals gas and whistling buoy (described under hurricane of Aug. 17, 1915), anchored in 42 feet of water, was carried 2½ miles to the westward.

Galveston Bar gas and whistling buoy was carried 1½ miles to the southwest.

Aransas Pass gas and whistling buoy anchored in 42 feet of water, latitude 27° 50′ N., longitude 92° 02′ W., was carried 5 miles nearly parallel to the coast and a little in toward the coast. This buoy weighs 8,000 pounds, the anchor 5,000 pounds, and 252 feet of chain weighing 3,528 pounds.

At Sabine Bank Lighthouse, 15 miles off Sabine Pass, cast-iron plates ⅝ inch thick, 27 feet above the surface of the water were crushed in and bent up by the waves. This place was about 125 miles to the right of the line of advance of the center. This is cited as showing the power of the wave in that part of the hurricane.

The area along the Gulf coast, which has been flooded by storm tides, is shown by the heights of the water given on figures 1, 2, 5, and 8.

The damage caused by this hurricane amounted to $20,272,000 and 284 lives were lost.

During the 20 years 1900 to 1919 hurricanes on the coast of the Gulf of Mexcio have caused damage to property amounting to $105,642,000, and 7,225 lives have been lost.

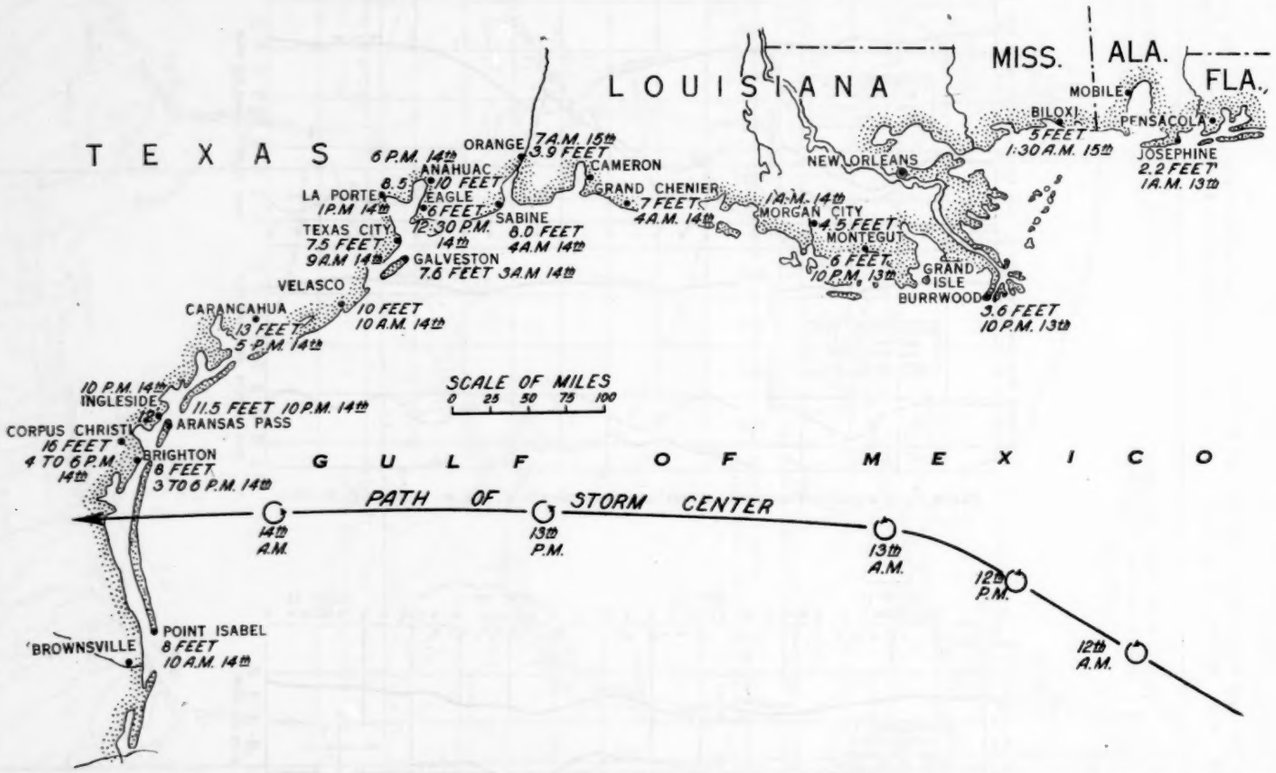


FIG. 8.—Height of storm tides along the Gulf coast above mean Gulf level and the time of their occurrence as related to the movement of the hurricane center through the Gulf of Mexico, September 11–14, 1919. This shows the storm tides in their relation to the path of a hurricane which moves in through the Florida Straits and thence across the Gulf to the Texas coast. The highest tide at stations, 30 to 50 miles inland, on bays and estuaries, occurred 8 to 12 hours later than at points on the coast line.—*I. M. Cline.*
NOTE.—The path of storm center shown here is subject to slight revision after all available reports have been carefully studied; e. g., the position on the 13th A. M. may have been farther west.—*F. G. T.*

CONCRETE KNOWLEDGE OF WINDS IN HURRICANES.

Storm tides, in conjunction with hurricane winds, are such destructive agencies that it is of primary importance that we have definite information relative to the distribution of the winds in these disturbances. These winds are the physical agents that furnish the energy that develops and carries the storm waves and tides to shores far in advance of the arrival of the hurricanes and on the approach of the cyclonic area causes the inundation of our coasts and the destruction of property and lives over considerable areas. Concrete information regarding the winds in hurricanes that produce the swells and tides is limited and, therefore, these are subjects that must be investigated in this connection. Definite knowledge of the action of these agents might be obtained if the wind directions and velocities in hurricanes could be charted simultaneously at a number of places in the different quadrants of the cyclonic area. However, the courses of hurricanes are mainly over water, and, therefore, it is not practicable to get simultaneous observations at a sufficient number of stations to give us definite knowledge of the actual winds in the different parts of the cyclonic area, and we must look for some other method by which we can obtain this information. We have the theoretical ideal conclusions and charts giving the direction and velocity of wind in hurricanes (3) (5), but these do not meet the requirements in the study of this subject, for here we have need for knowedge of conditions as they actually exist.

During the last 20 years two hurricanes have moved in at points on the middle Gulf coast, where sufficient

records have been kept to enable a very complete study of the actual wind directions and velocities in different parts of the cyclonic areas over water. These hurricanes while moving into extra-tropical regions, retained in a marked degree their tropical characteristics.

BIHOURLY STUDIES OF WINDS IN HURRICANES.

The hurricanes of September 29, 1915, and July 5, 1916, moved inland with the center of the first near Grand Isle, La., and the center of the latter east of Gulfport, Miss., and we secured very complete automatic records at New Orleans (1), and Burrwood (2), La., Mobile (3), Ala., and Pensacola (4), Fla. The southeastern portion of Louisiana, and the Mississippi, Alabama, and Florida, coasts are low lying, near sea level, and sparsely timbered. The physical features of the area over which these hurricanes moved, much of it being water surface, give as nearly ideal conditions for the study of the winds in the different quadrants of the cyclonic area during its passage as we can expect to find. These were typical hurricanes and both of great intensity. The progressive velocities of the cyclonic areas were determined for 100 miles after passing the latitude of Burrwood, La. The hurricane of September 29, 1915, advanced at the rate of about 12 miles per hour, and at this rate of progress the center was in the Gulf about 150 miles off the mouth of the Mississippi River at midnight of September 28. The hurricane of July 5, 1916, advanced with a velocity of 15 miles per hour, and it was centered in the Gulf about 275 miles off the Mississippi coast at midnight, July 4.

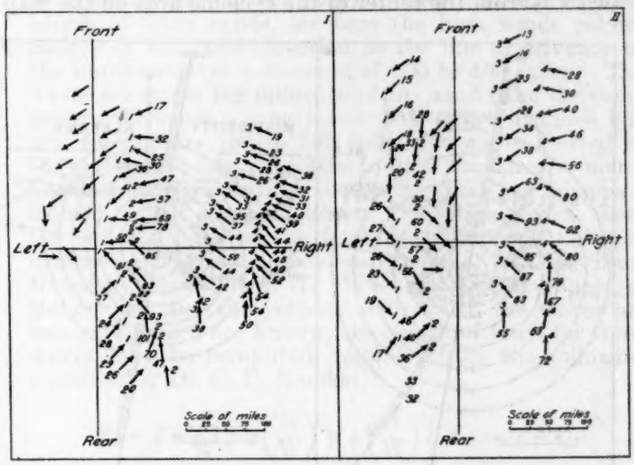
Based on a progressive movement of 12 miles per hour for the September 29, 1915, hurricane, and 15 miles per hour for the July 5, 1916, hurricane, maps were made every two hours during the passage of the hurricanes, using the automatic records at New Orleans (1), Burrwood (2), Mobile (3), and Pensacola (4), and observed pressure and wind directions from Morgan City and Lafourche, La., and Pass Christian and Gulfport, Miss. The sustained direction and velocity of the wind being of primary importance in producing waves, the prevailing direction for the preceding hour and the average velocity for the two hours preceding the time of each map have been used on these maps, instead of the direction and velocity at the hour. This gives us on the composite charts the sustained velocity of wind, not only for the two preceding hours, but during the entire passage of the hurricane. When the center of the hurricane of September 29, 1915, was 150, and that of July 5, 1916, was 275 miles distant from land, commencing at 2 a. m., at a time when the effects of the front of the storms were first being felt at Burrwood, La., and Pensacola, Fla., and at the end of each two hours following, the position of the center of the storm was carefully located geographically and charted from the automatic records mentioned above. A line was drawn on each map, through the center of the cyclonic area, the arrow pointing in the direction in which the storm was advancing at that time, dividing it into right and left segments; another line was drawn through the center at right angles to the first, dividing the storm into front and rear segments and also into quadrants.

COMPOSITE CHARTS SHOWING WIND DIRECTIONS AND VELOCITY.

From the maps we have prepared composite charts showing the actual winds, both direction and velocity, in different parts of the hurricane, viz., Charts I and II.

Chart I shows the distribution of wind direction and velocity in the hurricane of September 29, 1915, and Chart II shows the wind direction and velocity in the hurricane of July 5, 1916. In these charts the long arrow points in the direction of the line of advance of the hurricane and the intersection of the cross lines represents the center of the cyclonic area. The figures 1, 2, 3, and 4, at the points of the short arrows show the positions of the stations they represent, on the charts, with reference to the cyclonic center at the times when the wind directions and velocities were recorded. The arrow flies with the wind and shows the prevailing direction for the preceding hour. The figures at the butts of the arrows are the average wind velocities for the preceding two hours.

The composite wind charts for September 29, 1915, and July 5, 1916, were prepared in the following manner: The intersection of the cross lines on Chart I was placed over the center of the cyclonic area as shown on the map at 2 a. m. September 29, 1915, the long arrow on this chart pointing in the direction toward which the cyclonic



CHARTS I and II.—Composite wind charts. Prevailing wind direction for hour preceding and average wind velocity for two hours preceding time of observation in different parts of the hurricane. Chart I, September 29, 1915; Chart II, July 5, 1916.—*I. M. Cline.*

area was advancing at that time. The prevailing wind direction for the preceding hour and the average wind velocity for the preceding two hours as recorded on the map at 2 a. m. at New Orleans (1), Burrwood (2), Mobile (3), and Pensacola (4) were entered on Chart I, as shown by the first set or arrows and figures at the front of this chart. The positions of the numbers 1, 2, 3, and 4 at the points of the arrows bear the same relation to the intersection of the cross lines on this chart that the position of the stations they represent, occupied with reference to the center of the cyclonic area on the 2 a. m. map. Chart I was then placed over the 4 a. m. map in the same manner and the second set of figures from the front were entered on this chart, representing the wind directions and velocities as they appeared in that part of the cyclonic area on the 4 a. m. map. This was repeated for each map, the wind directions and velocities at the four stations being entered at their correct locations in respect to the center of the cyclonic area, on Chart I, at the end of each two hours as the cyclonic area advanced. The last set of entries in the rear of Chart I is for 6 a. m. September 30, 1915.

The same procedure was followed in preparing Chart II, composite wind chart for July 5, 1916, the first set of

arrows and figures on this chart being 2 a. m. July 5, 1916, and the last set being for 12 midnight, July 5, 1916. Fifteen maps were made for the September 29, 1915, hurricane, covering 30 hours, and there are 15 entries of wind direction and velocity from the front to the rear of Chart I, for each station except Burrwood, the record for that station being missing for the last three entries. The hurricane of July 5, 1916, moved rapidly and diminished in intensity very soon after reaching land; therefore, only 12 maps, covering 24 hours, were used in preparing the composite wind chart for that hurricane, and there are 12 entries of wind direction and velocity, from the front to the rear of Chart II, for each station. There was very little change in the intensity of these hurricanes during the periods covered by the maps used in preparing the composite charts. Each entry of wind direction and velocity on Charts I and II has been made so that the figure at the point of each arrow is the same distance, in the same direction, from the intersection of the cross lines on these charts that the station which it represents, New Orleans (1), Burwood (2), Mobile (3), and Pensacola (4), was from the center of the cyclonic area on the map

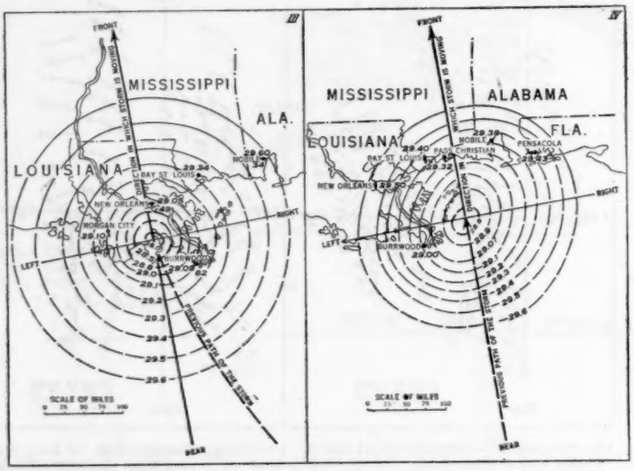


CHART III.—Hurricane, September 29, 1915. Pressure map at 2 p. m. midway of series used in preparing Chart I.

CHART IV.—Hurricane, July 5, 1916. Pressure map at 12 noon, midway of series used in preparing Chart II.—*I. M. Cline.*

at the hour when these directions and velocities were actually recorded.

The hurricane of September 29, 1915, recurved slowly during the 30 hours for which the maps were drawn. The greatest deviation from a straight line in the 360 miles traveled by the hurricane during this time was about 45 miles and occurred midway of the period. The hurricane of July 5, 1916, moved in nearly a straight line.

Chart III shows the pressure distribution and winds at 2 p. m. September 29, 1915, midway of the series of observations on which Chart I, composite wind chart, for that hurricane is based.

Chart IV shows the pressure distribution and winds at 12 noon, July 5, 1916, midway of the series of observations on which Chart II, composite wind chart, for that hurricane is based.

Charts I and II taken in connection with Charts III and IV show the relations of the winds to the isobars; both maps have been drawn from pressure reduced to sea level. These maps are considered preferable to composite pressure charts for these hurricanes.

WINDS IN DIFFERENT PARTS OF CYCLONIC AREA.

Wind directions and velocities shown on Charts I and II approximate closely what would have been found to prevail if simultaneous observations could have been taken at the point of each arrow on the charts and the direction and velocity of the wind determined at the end of any hour during the progress of the hurricanes of September 29, 1915, and July 5, 1916, respectively.

In the hurricane of September 29, 1915, one that recurved slowly, the wind velocity for four stations in the right-hand front quadrant averaged 43, and in the right-hand rear quadrant 52 miles per hour. The winds in the right-hand front quadrant near the path of the center blow across the line of advance, and 150 to 200 miles to the right of the line of advance of the center of the storm they blow at an angle of about 45° across the line of advance in the direction in which the hurricane is traveling, while in the rear right-hand quadrant the winds are mainly in the same direction as the line of advance of the hurricane. Effects of the wind, in the western segment of the September 29, 1915, hurricane, indicate velocities considerably less than those recorded in the right-hand segment. The highest wind occurred at a distance of 50 to 75 miles to the right of the line of advance after the passage of the center of the storm. The destructive power of the winds 40 miles east of New Orleans showed a greater force than at New Orleans. If we had automatic wind records for the September 29, 1915, storm from a point 50 miles east of New Orleans, such reports would show an increase in the wind velocities in the right-hand rear quadrant over those actually averaged from Chart I.

Burrwood, La., located in the right-hand segment, 50 miles to the right of the line of advance of the center of the cyclonic area, September 29, 1915, furnishes an excellent example for the study of the wind in that part of a cyclonic area at an individual station. Commencing at the time the center of the storm passed near that place, we get sustained wind velocities, in the rear right-hand quadrant, blowing mainly in a direction in line with the advance of the hurricane, as follows:

Sixty miles per hour or above prevailed for a period of 13 hours.

Seventy miles per hour or above prevailed for a period of 12 hours.

Eighty miles per hour or above prevailed for a period of 11 hours.

Ninety miles per hour or above prevailed for a period of 3 hours.

One hundred and eight miles per hour prevailed for 2 hours.

One hundred and sixteen miles per hour prevailed for one-third of an hour.

There was a gust with 1 mile at the rate of 140 miles per hour.

The wind velocity at Burrwood from 10 p. m., September 29, 1915, to 8 a. m., September 30, 1915, was not recorded, but the direction up to 9 a. m., September 30, 1915, continued mainly in the same direction as the line of advance of the hurricane. The wind velocity at 9 a. m., September 30, 1915, was 23 miles and by interpolating for the 11 hours following the 13 hours with a sustained velocity of 60 miles per hour or above, we find that an average velocity of 35 miles per hour prevailed. The average velocity was 85 miles per hour during the first 13 hours and 35 miles per hour for the next 11 hours after the passage of the center of the hurricane, making a total period of 24 hours with the average wind velocity exceed-

ing 60 miles per hour. During this time the wind was mainly in the same direction as the line of advance of the cyclonic area. Burrwood continued, during this 24 hours, in the rear right-hand quadrant of the cyclonic area.

In the hurricane of July 5, 1916, which progressed in nearly a straight line, the wind velocity averaged for all stations, 48 miles per hour in the right-hand front quadrant, 72 miles per hour in the right-hand rear quadrant, 29 miles per hour in the left-hand front quadrant, and 34 miles per hour in the left-hand rear quadrant. In this storm the stations in the left-hand and right-hand segments were nearly equi-distant from the path of the center of the hurricane.

Pensacola, Fla., located in the right-hand segment, 100 miles to the right of the center of the hurricane of July 5, 1916, furnishes a good example for the study of winds at an individual station in that part of the cyclonic area. Commencing at the time the center passed that station we get sustained wind velocities blowing mainly in a direction in line with the advance of the hurricane as follows:

Forty miles per hour or above prevailed for a period of 24 hours.

Fifty miles per hour or above prevailed for a period of 19 hours.

Sixty miles per hour or above prevailed for a period of 10 hours.

Seventy miles per hour or above prevailed for a period of 5 hours.

Eighty miles per hour or above prevailed for a period of 3 hours.

For a period of 24 hours after the passage of the center of the hurricane the average velocity was 59 miles per hour, with the wind blowing in a direction mainly in line with the advance of the hurricane. During this time Pensacola was in the rear right-hand quadrant of the cyclonic area.

The foregoing records from Burrwood and Pensacola, both on account of their location with respect to the centers of these storms and their positions on the coast, may safely be assumed to represent the winds which prevail in those parts of a hurricane in the open Gulf. The velocities may be greater or less, depending on the intensity of the hurricane.

The high winds which occur, as indicated in the above hurricanes, in the right-hand rear quadrant of the cyclonic area, are sustained velocities which persist in the same direction as the line of advance of the hurricane during the life of the hurricane. Taking into account the diameter and progressive movement of the cyclonic area, we get a length of fetch of 300 to 400 miles in the rear right-hand quadrant of storms such as those represented in Charts I and II, with the wind 35 to 100 miles per hour for 24 hours, blowing mainly in the direction of the line of advance of the hurricane.

DEVELOPMENT OF WAVES AND TIDES BY THESE WINDS.

The wind velocities in the left-hand segment of a cyclonic area are never strong as compared with the winds in the right-hand segment (3) and are not long sustained in the same direction over the same area. Furthermore, the progressive movement of the cyclonic area causes the winds over the greater part of the left-hand segment to recede continually from the waves which these winds create; and thus their force for developing waves is diminished. Therefore there can be no great development of waves in this part of the hurricane.

In the right-hand front quadrant of the hurricane the winds near the center of the cyclonic area blow in a direction which carries the waves they develop across the line of advance of the hurricane; but at a distance of 100 to 150 miles to the right of the line drawn through the center of the cyclonic area in the direction in which it is advancing the winds coincide more nearly with the direction of advance of the cyclonic area. Furthermore, in the front right-hand quadrant the winds change direction as a result of the progressive movement of the cyclonic area so rapidly that one direction does not persist over a distance or fetch of 75 miles during a period of as much as four hours. This condition, even with the high wind velocities that occur in this quadrant, would not furnish sufficient energy for large wave development.

In the right-hand rear quadrant the winds are more inclined toward the center and blow, in the main, in the same direction as the line of advance of the hurricane at sustained velocities averaging 72 to 85 miles per hour for 13 hours and 55 to 60 miles per hour for 24 hours. It is in this part of the cyclonic area that the greatest length of fetch exists, for here the high winds persist mainly in the same direction as the line of advance of the hurricane over a distance of 300 to 400 miles. The waves are under the influence of the wind from the same general direction not only over this entire distance but also for another 100 to 200 miles, for waves started in the rear do not pass out of the front of this area for many hours, during which time the fetch region has advanced a third to half a day's journey. For these waves, then, the actual length of the fetch is 400 to 600 miles in cyclones of the size and intensity similar to those illustrated in Charts I and II. When the size and speed of the cyclone and the velocity with which the waves are moving forward are known, the length of fetch for these waves may be computed, roughly, from the following equation by Dr. C. F. Brooks:

$$F_w = F + \frac{S}{W}F + \left(\frac{S}{W}\right)^2 F + \left(\frac{S}{W}\right)^3 F + \cdots\cdots\cdots$$

in which F is the length of fetch at any moment, S the forward speed of the cyclone, and W the progressive motion of the waves.

This sustained direction and velocity of the wind in the right-hand rear quadrant, prevailing during the life of the hurricane, furnishes the energy that develops and carries forward the larger waves of long length which move on through the smaller and shorter waves, pass on beyond the limits of the storm, and are carried by their inertia, in the line of advance of the hurricane, to shore long before even the front of the cyclonic area reaches there.

In this connection Eliot says (1): "The waves, when originally produced by the action of the moving air on the surface of the sea, move at a rate which is mainly dependent upon the velocity of the wind, and are hence called forced waves, because their rate of motion is determined by the body or action which produces them, viz, in this case the moving air. Waves when produced by such action do not cease when the action stops, or when they pass in their motion beyond the sphere of action of the producing winds. In such cases they pass onward in the same general direction as before, but gradually become smaller and smaller until at last they become imperceptible." He also in speaking of large waves, says: "Whatever explanation be adopted of the production of

these large waves, there is no doubt of the general principle that air moving over a water surface always produces waves, and that the magnitude of the waves is dependent upon the extent of the water area over which they blow and upon the force of the winds. It is evident that the strength of the swell or the distance at which it will be sensibly felt in the open sea, will depend partly upon the strength of the producing winds and partly upon the distance over which the producing winds act with no considerable change in direction. The rapid movement of air over the surface of the sea gives rise, by some species of cumulative action to a continuous succession of large parallel waves so long as the winds are fairly steady in character. Waves that are produced in this manner travel steadily onward in the same general direction so long as they meet no obstruction, and if they pass beyond the area of strong winds, they decrease slowly in height and force." He also says, in

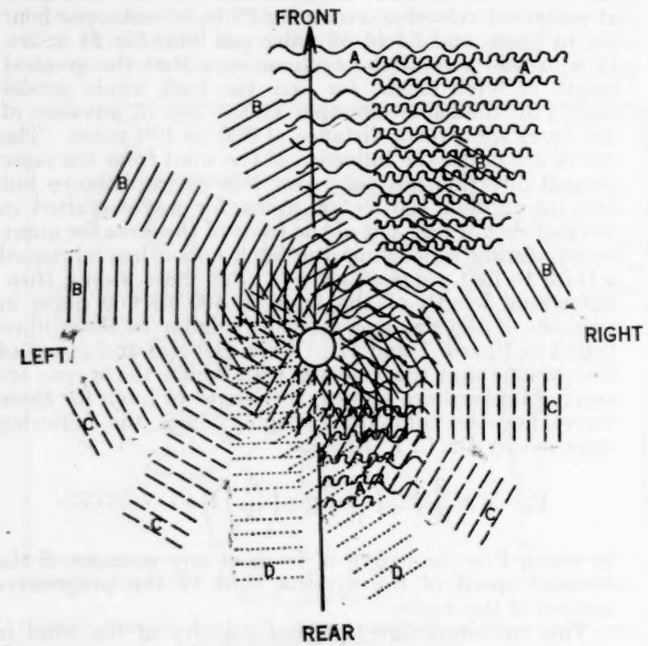


FIG. 9.—A. Swells of greatest length and magnitude, traveling in the line of advance of the hurricane.
B. Swells and waves of moderate length and magnitude in the front segment of the hurricane moving outward to right and left of the line of advance.
C. Swells and waves of smaller length and lesser magnitude in the rear segment of the hurricane moving outward to right and left of the line of advance.
D. Swells and waves of least magnitude moving outward from the rear of the hurricane.—*I. M. Cline.*

speaking of the swell produced by cyclones in the Bay of Bengal: "It has been distinctly felt when the storm was at least 400 miles distant in space and 48 hours distant in time. In these extreme cases the storm was approaching the coast where the swell was observed."

It appears that no effort has been made to illustrate the differences in the relative sizes of the waves and swells produced by the winds which prevail in the different parts of the cyclonic area. Col. Reid, as early as 1849, gave us a diagram illustrating the power of the winds of a cyclonic storm to give rise to swells moving outward in all directions from the storm area, (1) but he did not differentiate between the size and persistency of the swells produced by the winds in the different parts of the storm. With the wind directions and velocities which prevail in the different parts of the cyclonic area, as shown in the foregoing discussion and on Charts I and II, we are able to illustrate the relative size and persistency of the swells which move out from the different parts of the cyclonic area and these are illustrated in figure 9, where the size of the swells going out from each part of the cyclonic area is shown to bear a certain and well-defined relation to the producing winds.

CONCLUSIONS.

1. The waves and swells of greatest size and length are developed in the rear right-hand quadrant of the cyclonic area and move through the smaller waves in the front of the storm and are carried by inertia to shore in the direction in which the cyclonic area was advancing at that time. The waves sent out in other directions, being smaller and shorter, do not persist long after leaving the cyclonic area and soon flatten out and disappear.

2. The transference of water with the long waves and swells causes rises in the water along the coast, which increase as the storm approaches. The rise in the water on the coast in front of the line of advance of the cyclonic area, beginning 12 to 24 hours after the hurricane enters the Gulf, indicates the rapid movement of the waves through the storm area and across the Gulf. From a study of the movements shown on the different charts and figures with this paper, the speed varies from 30 to 45 miles per hour. The rapidity with which the waves travel depends both upon the extent of the cyclonic area and the intensity of the winds that develop the waves and swells. The water rises at the shore in the front, and to the right, of the point toward which the center of the hurricane was moving at the time the waves started on their journey.

3. The rise at shore, of the water from the hurricane, shows long in advance of any change in the barometer. Take, for example, the hurricane of September 11–14, 1919. When the barometer at Burrwood, New Orleans, Galveston, and Corpus Christi was either stationary or falling only a few hundredths of an inch, the water, first at Burrwood, later at Galveston, and then at Aransas Pass was rising in feet, telling the story of the movement, and of the change in the course of the storm as plainly as could possibly be told.

4. In using the information conveyed by the tides in forecasting the movements of hurricanes, the tides as predicted by the Coast and Geodetic Survey should be plotted for each hour whenever a storm appears in the Gulf. The height of the tide above mean low tide should be telegraphed from coast stations with each observation and these should be plotted over the predicted tides. The place where the water exceeds the predicted tides and continues rising is in the line of advance of the hurricane at the time that water started on its journey.

5. The intensity and extent of the hurricane is indicated when the disturbance is at a considerable distance in space and time, by the rapidity of the rise in the water and the extent of the coast over which the rise is taking place.

6. The time between the commencement of the rise in the water at shore and the arrival of the hurricane will depend upon the rapidity with which the cyclonic area is advancing and the intensity of the hurricane.

7. If the point of greatest rise shifts to the right or left, this indicates that the storm is changing its course in that direction toward which the increased rise is taking place.

8. When the crest of the storm tide is coincident with the crest of the regular tide the height of the water

will be greater by more than one foot for hurricanes of equal intensity than when the crest of the storm tide is coincident with low tide, and in forecasting storm tides this must be borne in mind.

9. The regular tides are not obscured at any time by the storm tide, except at or near the point where the center of the storm moves inland, and then for only about twelve hours before the passage of the center of the hurricane.

10. The highest water occurs a few miles to the right, and about the time, of the passage of the center of the cyclonic area. At points on the coast some distance to the right of the line of advance of the center, the highest water occurs on a line drawn through the center of the cyclonic area at right angles to the line of advance of the hurricane, about the time of the passage of the center of the storm across that line.

11. The high water extends for only a short distance to the left of the point where the center of the storm moves inland. High water, however, is experienced to the right of the center for a distance of 100 to 200 miles.

12. The water commences rising at the shore toward which the cyclonic area is advancing in less than 24 hours after the center of the cyclonic area has entered the Gulf. The waves and swells which give this rise must have moved through and out of the rear right-hand quadrant of the storm area within 12 to 15 hours after the center of the storm entered the Gulf of Mexico. This indicates that with a fetch of 150 to 200 miles in the rear right-hand quadrant of the cyclonic area the winds furnish sufficient energy to develop waves and swells of a size and length that travel 30 to 45 miles per hour, reaching the middle Gulf coast, 400 miles distant, in 10 to 15 hours, and the Texas coast, 800 miles distant, in 15 to 20 hours.

13. Strong currents are created in the right-hand segment of the cyclonic area which move in the main coastwise toward the line along which the cyclonic area is advancing. The fact that two gas and whistling buoys in August, 1915, and three in September, 1919, were carried 2 to 8 miles nearly parallel to the coast, shows the force of these currents. If these buoys had been moved by waves they would have been carried in toward the shore and not along the coast.

NEITHER A STORM NOR A TIDAL WAVE.

14. The high water attending the hurricane is frequently referred to as a "tidal wave," or "storm wave," but it is not a wave in any sense of that term. It is a cumulation of the water from successive "storm waves" reaching shore, covering a period of two or more days, with a gradual rise which increases as the center of the storm approaches. The "storm tide" results from the physical forces of the hurricane, driving the large waves forward and transferring the water in the same direction as the line of advance of the hurricane. In the open sea this storm tide is not so great, probably not exceeding, in the greatest storm, more than 5 feet. The obstruction formed by the coast line acts as a barrier and the water gradually banks up as it does against a dam across a stream. The rise in the water at shore is frequently against opposing off-shore winds as was the case at Galveston, Tex., in 1900 and in 1915, and at Corpus Christi, in 1919. In such cases the off-shore winds force the water back on the storm, retarding the rise; then when the winds shift and come in with the storm, the rise in water is much more rapid and consequently more destructive. The diminished pressure near the center of the hurricane will have some effect on the height of the water. The weight of 1 inch of mercury is equal to that of about 1 foot of water. The increase in the height of the water due to diminished pressure at Galveston, for example, in 1900, with the barometer 28.48 inches, could not have exceeded, under most favorable conditions, 1.5 feet, whereas the storm tide was 15 feet.

RECORDS OF WAVES AND SWELLS.

There are no records available for use in the study of the individual storm waves and storm swells and groups which reach the coast and cause the storm tides. A knowledge of the size and speed of these would aid in the study of the movements of water in hurricanes. A definite knowledge of these waves would aid in determining the location and intensity of hurricanes. Observations should be made along the coast, especially when hurricanes are approaching, of the speed and direction of waves and swells. The velocity of water waves and ripples is determined by the wave length. "Wave velocity = wave length × wave frequency."

Fleming says this relation may be stated in another manner: "We call the period of a wave the time taken in making one complete movement. The period in time, is, therefore, inversely proportional to the frequency. Hence, we can say that the wave length, divided by the periodic time, gives us the wave velocity. * * *"

"A formal and exact proof of the law connecting speed and wave length for deep-sea waves requires mathematical reasoning of an advanced character, but its results may be expressed in a very simple statement by saying that in the case of waves in deep water, the speed with which the waves travel, reckoned in miles per hour, is equal to the square root of $2\frac{1}{4}$ times the wave length measured in feet * * *."

"The above rule for the speed of deep-sea waves, viz, wave velocity = square root of $2\frac{1}{4}$ times the wave length combined with the general rule, wave velocity = wave length multiplied by the frequency, provides us with a useful practical method of finding the speed of deep-sea waves which are passing any fixed point * * *." Count the number of waves which pass the fixed point per minute and divide the number into 198; the quotient is the speed of the waves in miles per hour. Thus, if ten waves per minute race past a fixed buoy, their velocity is nearly 20 (19.8) miles per hour. If V is the velocity of the wave in feet per minute, and V' is the velocity in miles per hour, then $V' \times \frac{5280}{60} = V$. But $V' = 2\sqrt{\frac{1}{4}l}$ and $V = nl$, where "l" is the wave length in feet and "n" the frequency per minute; from which we have $V' = \frac{198}{n}$, or the rule given in the text.

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Automatic tide records for Port Eads and Burrwood, La., and Fort Morgan, Ala., have been furnished by the district engineers, United States Engineers Corps, New Orleans, La., and Mobile, Ala. Staff-gage tide

records for 1909, 1915, and 1919, and other important matter for Galveston, Tex., have been furnished by the district engineer at Galveston, Tex.

Automatic tide records at Galveston for 1906, 1909, 1916, 1917, and 1919, and important references have been furnished by the Superintendent and other officials of the United States Coast and Geodetic Survey, Washington, D. C.

Reports from lighthouses in the Gulf, and the movement of buoys in storms have been furnished by the Inspector of the Light House District, New Orleans, La.

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THE FORECASTING OF SWELLS ON THE COAST OF MOROCCO.

By LOUIS GAIN.

[Abstracted from Revue général des Sciences, July 15, 1919, pp. 408-411.]

The great damage which was frequently wrought to shipping along the coast of Morocco by great ocean swells has been the subject of a number of studies. The author's studies have led him to the conclusion that these destructive swells can be forecast from the pressure distribution in the portion of the Atlantic to the east and northeast of Morocco. The conclusions, based upon the study of the effects of 210 low-pressure areas, are as follows:

I. A swell produced at Casablanca is the consequence of—

1. A depression on the ocean between the Azores and the British Isles, and light northwest winds in the region between the African coast and the depression. If the depression is intense, the swells will be correspondingly greater. These waves originating within the LOW require from 2 to 5 days to reach the coast of Morocco.

2. A depression moving eastward between the Azores and Portugal. In this case the swells are rarely large at Casablanca. They require from 24 to 48 hours to reach the coast.

3. Secondary depressions arising from LOWS in the north, moving southward over western Europe from the region of Norway and the British Isles, and giving rise to depressions over the Mediterranean.

II. A swell is weakened or made ineffective at Casablanca—

1. When there is an anticyclone over the region between the coast of Morocco and the depression.

2. When the depressions pass north of the British Isles.

3. In the case where depressions descend upon Europe when passing between Norway and the British Isles.

4. When an intense LOW with strong winds moves rapidly eastward.

The forecasting of swells can be either made directly at Casablanca by means of comparison of the daily wireless reports from Paris with those of the preceding day, or at Paris; the forecast itself can be forwarded to Casablanca. The author considers that more study should be given the problem, but that it is now possible to avoid such catastrophes as have been experienced along the coast of Morocco.—*C. L. M.*

MEAN SEA LEVEL.

By D'A. W. THOMPSON.

[Abstract reprinted from *Science Abstracts*, Nov. 29, 1919, p. 504. Article in *Nature*, Aug. 21, 1919, pp. 493–495.]

The level of the sea, or more generally, the form of its surface, is the resultant of two kinds of forces after eliminating the effects of the tides. There is the action of the sea currents and densities (intrinsic forces); and that of wind and barometric pressure (extrinsic forces). Witting thus summarizes the effects of the extrinsic forces: (1) Every barometric distribution of any permanency produces a deformation of the surface of the sea. (2) The ascending slope so produced is not identical in direction with the barometric gradient, but deviates to the right in the Northern Hemisphere. (3) The amount of slope is greater than that which would correspond with the hydrostatic pressure, induced by the barometric distribution. With regard to the intrinsic forces we know enough to choose a point at sea where no movements are caused by the distribution of densities. This is the zero pressure level. A geodetic surface drawn through this point may be considered the datum level. Proceeding outward from such a point, Witting has calculated the hydrodynamical gradient due to densities, and added to it the effect of barometric pressures. He has found that levels thus calculated for the Baltic area agree to a surprising closeness with the determinations of precise levels.

The question of secular changes of level is beset with difficulties. But assuming the coast from Wismar to Pillau has kept at constant level, Witting mapped the changes in level in the Baltic from 1898 to 1912. Some minor fluctuations are related to seismic phenomena; e. g., there was an interruption in the general upheaval at the time of the Scandinavian earthquake, 1904. For some centuries past the elevation of the Fennoscandian

lands has gone on at the present rate. The phenomenon has been approximately the same for 6,000 years, but during the Bronze Age and just after, it was possibly slower. The more ancient phenomena are difficult to discuss, as a damming up of the Baltic outlet would produce results similar to actual land elevation.—*W. A. R(ichardson)*.

THE WAVE-RAISING POWER OF NORTHWEST AND SOUTH WINDS COMPARED.[1]

I recall that sailors on the Great Lakes have claimed that a wind of a given velocity in winter caused a higher sea than a wind of the same velocity in summer. They attributed this to the fact that in summer the relatively cold water of the Lakes reduced the temperature of the surface air layers, producing a temperature inversion. As a result, a wind movement in the upper air layers, which might be strong at the height of the masthead, would be light at the surface of the water. In winter, on the contrary, the air is generally colder than the water of the Lakes, the air movement is felt down to the surface and causes high seas.

Perhaps a similar explanation may apply to the difference in wave-raising power of northwest and south winds, since in the northern hemisphere the former are apt to be the colder.—*H. H. Kimball.*

[1] Cf. February, 1920, issue MONTHLY WEATHER REVIEW, pp. 100-101.

DISCREPANCIES BETWEEN ÅNGSTRÖM AND SMITHSONIAN INSTRUMENTS.

By C. G. ABBOT, Director, Astrophysical Observatory.

[Smithsonian Institution, Washington, May 3, 1920.]

In the issue of the MONTHLY WEATHER REVIEW for November, 1919, Dr. A. K. Ångström has three papers of great interest. In one paper he gives comparisons which must be highly gratifying to all those who are interested in the constancy of the scale of radiation measurements. He shows that in the seven years, 1912 to 1919, there had occurred no appreciable change in the Ångström and Smithsonian scales relatively to each other. During this interval Smithsonian observers have made several unpublished comparisons against the Standard water-flow pyrheliometer No. 3, which also supported the constancy of the Smithsonian scale with very satisfactory accuracy of experimentation. Thus we may be sure, it seems to me, that no change in the scales on which pyrheliometric and spectrobolometric measurements have been made for many years has occurred so large as 1 per cent.

Dr. Ångström finds the Smithsonian scale to be 3.2 per cent above the Ångström scale. Of this discrepancy, he admits that 1.8 per cent is due to the two small sources of error which he discussed in a former publication. The other 1.5 per cent he is inclined to throw upon the Smithsonian scale.

In regard to this latter suggestion, I am only able to say as was said in Volume III of the Annals: "The system which we call 'Smithsonian Revised Pyrheliometry of 1913' rests on 72 comparisons on 20 different days of 3 different years with 3 standard pyrheliometers of different dimensions and 2 widely different principles of measurement, all capable of recovering and measuring within 1 per cent test quantities of heat, and all closely approximating to the 'absolutely black body.' The 72 comparisons, 40 at Washington, 32 at Mount Wilson, were made in 6 groups. The maximum divergence of the mean results of these groups is 1 per cent. Hence it is believed that the mean result of all the comparisons made under such diverse circumstances must be within 0.5 per cent of the truth. The probable error is 0.1 per cent. It is believed that this standard scale is reproducible by the secondary pyrheliometers with the adopted constants given to within 0.5 per cent."

In Volume III of the Annals the determination of the constants of the Standard pyrheliometers Nos. 2, 3, and 4, and the comparisons which have been made with them, are given with great detail from pages 55 to 72, so that readers will be able to see for themselves at every step how far the claim just quoted is justified.

It appears to me that before we can be warranted in admitting Dr. Ångström's suggestion that the Smithsonian scale is 1.5 per cent in error because it exhibits that degree of divergence from the corrected Ångström scale, we ought to have equally full details of measurements and comparisons on which the Ångström scale and comparison between it and the Smithsonian scale rest.

Especially I would call attention to these points:

1. Since the electrical resistance of the Ångström strips in the standard instruments is measured by a potentiometer device between points of known distance apart it would be possible, by making the Wheatstone's bridge measurement of the actual resistance between the terminals of the Ångström strips, to determine the actual distance through which the heating of the strip occurred rather than to make an estimation with regard to that distance, as was done by Dr. Ångström in his experiments which led him to the correction of 1.3 per cent.[1] This is very important, for he will agree that the mathematical theory of the subject shows that if the difference in length between the sun-heated and electrically-heated portions of the strip should be above his estimate of it the magnitude of the correction would very rapidly grow.

2. Since the width of the strip is only 2 mm., accuracy to 0.5 per cent demands that the width should be known to within 0.01 mm. In view of the presence of the particles of platinum black and of soot required for blackening the strips, is it possible to define the edges of the strips to within this degree of accuracy? Dr. Knut Ångström,[2] the distinguished inventor of the instrument, states with regard to this point: "Since the coating with lampblack leaves the edges a trifle rough, an error of 0.01 mm. in measures of the width evidently can not be avoided, which in the width of the strips here used may make an error of 0.5 per cent in the final value."

3. Although the measurements of Kurlbaum indicate that the effect of introducing the heat at the front of the strip when heated by the sun, as against introducing it through the body of the strip when heated by the current, produces but a small amount of error, is it quite certain that the blackening Dr. Kurlbaum experimented with is so nearly similar to the blackening of the Ångström strips that this correction is as small for the Ångström pyrheliometer as for the Kurlbaum metal foil? Dr. Ångström's computations lead him to admit 0.5 per cent for this effect. But the magnitude of it must depend on the intimacy of contact between each individual strip and its blackening. Is this known to be uniform and that negligible opposition to the flow of heat occurs

[1] Astroph. Jour., vol. 40, p. 279. It is by no means certain that the ends of the strips electrically were at the edges of the pole pieces visually.
[2] Astroph. Jour., vol. 9, p. 336.

at the boundary? In short, is it not necessary to determine the error for the strips of the actual instruments which serve to fix the Ångström scale, when accuracy to a few tenths of 1 per cent is claimed for that scale?

4. Although K. Ångström, Coblentz, and Royds have determined the reflecting power of certain surfaces when blackened in certain ways, is it sure that the blackening of the strips of the actual instrument on which the Ångström scale depends is so exactly similar to the blackening of their surfaces that the correction for reflection is identically the same? Dr. Knut Ångström [3] gives results of his determinations of this correction and then states: "If we take the coefficient of absorption of these surfaces as constant for different wave lengths and equal to 98.5 per cent then we make at most an error of 0.5 per cent in the determination of the intensity of radiation."

It appears to me that until all of these points are settled to the same degree of certainty and published with the same degree of fullness with which the Smithsonian scale has been set forth, it is not justifiable to make such a suggestion as Dr. Ångström has offered.

At the same time, I am not disposed to claim perfection for the Smithsonian scale, and if equal weight can be thrown upon any other determination which indicates a different scale, I am quite willing to divide the discrepancy equally between the two, but I must require that the weights of the two determinations be equal before such equal division of the discrepancy can be made. Dr. Ångström, however, after correcting his scale to his best knowledge, gives it infinite weight rather than equal weight to the Smithsonian scale in dividing the discrepancy between them.

In another paper, Dr. Ångström gives results of comparisons between his instrument for measuring sky radiation and a copy of the pyranometer purchased by the Weather Bureau from the Smithsonian Institution. He states that the average result of the comparisons showed agreement within 2 per cent, but that some of the comparisons differed by as much as 6 per cent, and he is inclined to throw this larger divergence upon a certain source of error in the pyranometer. This source of error is the one which was pointed out at length in a paper entitled "On the Use of the Pyranometer," [4] by C. G. Abbot and L. B. Aldrich.

The nature of the error is this: When exposed to daylight sky, the nickel-plated cover absorbs about 30 per cent of the solar rays which meet it, and thereby is warmed and warms the glass hemisphere below it by air convection. When the nickel cover is removed the glass can cool rapidly by long wave-length radiation to the colder atmosphere and to space. As the glass is almost completely transparent to solar rays, it is hardly warmed at all by them. Hence the glass, after exposure, grows cooler than before, and as it subtends a full hemisphere, it tends strongly to reduce the temperature of the blackened strips below, thus causing the gradual decrease of the galvanometer deflection due to opening the instrument to the skylight.

This source of error varies in its influence from place to place, depending upon how strong is that which we call "nocturnal radiation," and this, in turn, depends upon the quantity of water vapor prevailing and the temperature of the air immediately above the instrument. At Washington, and in general in moist climates, and especially in summer, the outgoing radiation is small,[5] so that the error tends to be small also. At a high-level station, like Mount Wilson or Mount Whitney, the magnitude of the disturbing cause is considerably larger.

We attempted to do away as much as possible with this source of error by introducing a reading of the galvanometer by the method of first swing. The galvanometer which we were accustomed to use had a time of single swing of 4 seconds. In this short interval we believed that the inner surface of the glass hemisphere could hardly change temperature sufficiently to produce any influence on the strips. The question now at issue is whether we were misled in this belief to the extent that errors of 5 or 6 per cent might have arisen in Dr. Ångström's comparisons, made in August in Washington.

In order to test the matter, Mr. Aldrich and I have performed the following experiment. We supported a large-bottomed teakettle, partly filled with ice water, at a short distance centrally above the pyranometer. Between it and the pyranometer we introduced an asbestos screen. Immediately beneath it was attached a nitrogen-filled tungsten lamp. When this lamp was lighted the intensity of radiation which it furnished to the pyranometer was found to be 0.20 calories per square centimeter per minute. When the screen and lamp were swung aside, the lamp extinguished, and the glass removed from the pyranometer, we found that the outgoing radiation from the pyranometer to the cold bottom of the teakettle was 0.097 calories per square centimeter per minute.

Having placed the screen and lamp in position above the pyranometer and lighted the lamp, we waited until the galvanometer had reached a perfectly constant zero We then suddenly withdrew the screen and lamp, extinguishing the lamp, so that the room was in darkness, and as quickly as possible, within 2 or 3 seconds, opened the shutter, so that the glass of the pyranometer was exposed to the cold bottom of the teakettle. In this way we reproduced very approximately the conditions which we have just described when measurements are made upon the sky, but with the difference that after the exposure of the glass no short wave-length radiation came through it to disturb the galvanometer. But the cooling of the glass would go on quite as fast under these circumstances as if it had been actually exposed to a negative skyward radiation stream of intensity of 0.10 calories per square centimeter per minute, after having been for a long time under the influence of incoming sky radiation of the intensity of 0.20 calories per square centimeter per minute.

As a result we found that in the first 5 seconds after exposure of the glass to the cold teakettle, a deflection averaging in three experiments 0.9 millimeter was produced, which on being compared with the deflections due to the introduction of current into the pyranometer strip proved to correspond to 0.0014 calories per square centimeter per minute. In other words, for a galvanometer whose time of first swing is 5 seconds, the error to which Dr. Ångström calls attention would be of the magnitude of 0.0014 calories per square centimeter per minute, which would be of about the order of 1 per cent compared to the sky radiation which would be observed. The error could be very materially reduced—probably to a third or a fifth of these dimensions—by using a galvanometer of only 3 seconds single swing, because the plotted curves of the observations show that the change of temperature due to the cooling of the glass did not set in in the pyranometer

[3] Astroph. Jour., vol. 9, p. 339.

[4] Smith. Misc. Coll., vol. 66, No. 11.

[5] Smaller, of course, by day than by night.

strips till one or two seconds after the exposure had been made. If, however, the time of swing of the galvanometer was larger than 5 seconds—10 seconds, for instance—the curves show that the error would increase nearly proportionally to the time of swing of the galvanometer.

I am not aware what was the time of swing of the galvanometer which Dr. Ångström employed in his comparisons, but I suppose it to have been of the order of 3 or 4 seconds, which is that which we customarily employ in pyranometer observations. If this is the case, I am of the opinion that it is quite impossible that error of the order of 5 or 6 per cent, such as he calls attention to, could have been due to this source. The tendency of the error is, of course, to make our instrument read too low. Dr. Ångström does not say in what direction the discrepancy between the two instrument lies.

FORECASTING THE WEATHER ON SHORT-PERIOD SOLAR VARIATIONS.

By CHARLES F. MARVIN, Chief U. S. Weather Bureau.

[Washington, D. C., April 4, 1920.]

In the remarkable paper [1] cited below, Mr. Clayton claims he has established important relations between high and low values of the day-to-day intensities of solar radiation, E_o', as measured by the Smithsomian Institution, chiefly at Mount Wilson, Calif., and Calama, Chile, and the values of the mean temperature at Buenos Aires. By means of these relations he claims material improvements in forecasting the weather are made possible. These investigations are an extension of earlier studies by which this author [2] endeavored to show that the whole earth responds in a complex but definite manner to the small changes of a few per cent in the reduced values of solar radiation as measured at Mount Wilson, Calif.

The forecasting value and possibilities of knowledge such as Mr. Clayton claims to have disclosed is obviously very great and important *provided his claims are true.* The writer, however, quickly became firmly convinced, purely from basic principles, that Mr. Clayton, who seems to regard the day-to-day changes in the observed values of solar intensity are mostly of solar origin, is quite in error. Indeed, great harm is being done to the cause of weather forecasting and the real progress of science by the wide dissemination of unrefuted representations of this character.

The whole matter seems to the writer to be a case of the seemingly complete disregard in the discussion of data of the material errors of observations and of the laws and operations of chance. Such a course has necessarily resulted in a grave misinterpretation of an excellent mass of observational data. Urged by these convictions, the writer has endeavored to evaluate, if possible, the unavoidable random and partially known dominant errors of measurements of solar radiation. This study was approached with a full belief in some solar variability. The results, however, unequivocally show that the observed changes in day-to-day values of radiation are very largely due to the aggregate of all the unavoidable sources of error of determination, all wholly terrestrial. The possible frequent and irregular variations of solar intensity from day to day or over an interval of a few days must be quantitatively such a small fraction of 1 per cent that it can not be satisfactorily evaluated from the existing data even including those now being secured by the new pyranometric method of observation. Such variations, if any actually occur, must be so small as to be quite inconsequential as a controlling factor of the weather and temperature of to-morrow or the next few days at any particular locality.

The only question the writer discusses in this paper is the *changes* of intensity from *day-to-day* or from some daily value of intensity to the next daily value observed a few days later. These are the variations in observed values which Mr. Clayton has used as the basis of correlation between solar intensities and temperature changes at Buenos Aires.

The writer particularly desires to avoid making any statement either for or against slow long-period solar changes, that is, changes over a few weeks, months, seasons or years, for example. He distinctly desires to leave open the question of regular or irregular changes of this character. The manner in which terrestrial weather responds to such changes can not be intelligently discussed until such changes have been conclusively shown to occur and been at least fairly evaluated in amount. An investigation with this object in view is also in progress.

The real question now at issue is simply the *variability* of daily or quite frequent *observed* values of solar intensity outside the earth's atmosphere, and how much, if any, of this variation is caused by true solar changes and how much caused by errors of measurement and varying depletions of large masses of the atmosphere which transmit all incoming radiation before measurement of its intensity.

Seemingly, one of the most direct, if not the best methods of solving such a problem consists of a critical evaluation, by means of well-known statistical methods, of the *variation* of the observational data of which an excellent body of over 1,500 frequent values of intensity is now available.

Within the past few weeks the writer has made a somewhat hasty preliminary review of these data, and it seems proper to briefly mention in this preliminary note certain important facts which seem to stand out unequivocally.

(1) The frequency distribution of the data is nearly Gaussian, that is, it nearly conforms to the normal error curve of statistics. Therefore, the data may be discussed by the methods of least squares.

(2) The distribution is not entirely elemental, but in this feature it reflects and justifies the composite make-up which the theory of the variations as expressed in equation (1) below calls for.

(3) There is only slight skewness in the distributions, which varies a little in amount and kind (positive or negative) according to the particular group of data analyzed. The evidence from skewness justifies the assertion that for observations at Mt. Wilson, Calif. by the bolographic method and on the average, *changes* in transmission of the atmosphere during observations tend to give a preponderance of slightly too low values of intensity and correspondingly too high values of the coefficient of atmospheric transmission.

(4) *Changes* of transmission during observations also cause greater scattering and dispersion of values than would otherwise occur, thus imposing upon the data many false variations due entirely to atmospheric, not solar, causes.

[1] Variation in Solar Radiation and the Weather, by H. Helm Clayton. Published simultaneously in Spanish in the Boletin Mensual Oficina Meteorologica Argentina, and in English in Smithsonian Miscellaneous Collections, vol. 71, No. 3.

[2] Smithsonian Miscellaneous Collections, vol. 68, No. 3.

(5) *Values of* E_o *versus* E_o'.—The Astrophysical Observatory publishes two values of solar radiation intensity, designated, respectively, the reduced value E_o and the final value E_o'. The latter is derived from the former by the application of a secondary correction for water vapor found to be necessary because of a certain correlation where none should exist between E_o and weather and sky conditions at Mount Wilson. The values E_o are derived from the rigorous reduction of the observations according to the Langley-Bouguer theory. The secondary water-vapor correction is always additive and increases the value of E_o in the long run, and by trial it is found the correction does not reduce the scattering or dispersion of the values of E_o as is required by the theory. The writer considers the values of E_o most appropriate for fundamental studies of solar intensity data. Mr. Clayton has used only values of E_o', but one value is just as good as the other for his particular studies.

(6) The principles of physics and laws of errors lead to the following basic equation:

$$\sigma = \sqrt{\frac{\Sigma v^2}{n}} = \pm\sqrt{s^2+\alpha^2+i^2} \qquad (1)$$

in which σ is the gross standard deviation of the data due to all causes, that is σ is the semiparameter of the Gaussian curve of best fit to any group of n observations which furnish the residuals Σv^2; s is the part of the deviation caused by solar changes, if any exist; α is the measure of the variations due to purely atmospheric effects or controls, and i is the part of the measure of gross variation attributable to instrumental errors. The latter is the measure of errors caused by operations *within the observatory* as contrasted with α which arises only by what happens to the incoming radiation during its transmission through the changing air mass. These two latter causes of variations are wholly terrestrial and can and often do exercise a powerful terrestrial control on a single value of radiation intensity.

Everyone will admit, we believe, that material and finite values must be assigned to α and i before we can speak in quantitative terms of solar variability, no matter what method of observation is employed. Seemingly, no adequate effort to do this has yet been made. It is clearly most improper to assume that α and i are wholly negligible in single values of intensity, yet, in effect, this is necessarily done when the day-to-day *observed* values of radiation (or even the average of several values selected because they are extreme) are used in establishing correlations between *alleged* solar changes and terrestrial weather. Results thus secured are clearly dependent upon the errors of measurement represented by the quantities α and i, and must therefore be distrusted.

If E_o is the mean value, and if σ is the standard deviation of a group of n observations, then by least squares the probable error or probable variation, ϵ, of a single daily value in percentage amount will be

$$\epsilon = \pm\frac{0.6745}{E_o}\sqrt{\frac{n\sigma^2}{(n-1)}} = \frac{0.6745}{E_o}\sigma \text{ if } n \text{ is large.} \qquad (2)$$

Now a gross value of ϵ resulting from *all* causes of variation is easily computed from the data. For good and bad observations, as a whole, it is found the value of ϵ rarely exceeds ± 1.3 per cent for bolographic observations, at Mount Wilson, Calif.[3] whereas taking good and excellent observations ϵ falls generally below 1 per cent, and Dr. Abbot's new method of observation by means of the pyranometer in use at Calama, Chile, yields unselected data (292 values) which show a gross probable error of only 0.79 per cent, and less in later data. The sky conditions at this station appear to be much superior for solar work to those at Mount Wilson, and the gross probable error of a single value by the bolographic method at this station was only 0.94 per cent for all observations (247) July, 1918 to July, 1919.

The smallness of these quantities alone signifies high intrinsic merit in the observational data and furnishes a very narrow margin for frequent and irregular short-period solar variations. In fact, the solar radiation investigations conducted by Dr. Abbot constitute a monumental research of the highest possible order and command only the admiration of all. The representations made in this note have to do only with a question of the entire correctness of the interpretation put upon the irregular day-to-day and short-period changes in observed values.

There is no evidence in Mr. Clayton's paper that the inherent errors of observations of solar radiation have been evaluated by him or considered in any way, and the suspicion is justified that the whole fabric of his correlations rests very largely upon the errors caused by terrestrial controls in making observations of solar radiation at Mount Wilson. The writer has no comment to offer here on a claim which may be made that Mr. Clayton's work at least proves that there is a correlation between Buenos Aires temperatures and the undefined atmospheric states at Mount Wilson associated with extremes of solar intensities.

This preliminary note is submitted at this time to justify and support certain adverse criticisms made by the writer in the discussion of the paper read by Dr. Abbot at the meeting of the Washington Academy of Sciences [4] January 29, 1920, presenting the results of Mr. Clayton's studies.

The whole question of short and long period solar variability, and the terrestrial response thereto in terms of weather, is obviously one of great importance to applied meteorology and to science in general. It is very necessary, therefore, that the splendid observational work done by the Astrophysical Observatory be generously supported and extended, in order that the outstanding and unsettled questions of the correct interpretation of the observations may be brought to a conclusion with which all students may agree.

A more detailed statement of the grounds for the writer's views and the statistical basis for his conclusions is in course of preparation and will be offered in the near future.

[3] Dr. Abbot has kindly supplied me in advance of publication with manuscript copies of all observations made at Mount Wilson during the years 1912 to 1918, inclusive. These are thankfully acknowledged.

[4] Journal of the Washington Academy of Sciences, April, 1920, vol. 10, No. 8, pp. 226 to 236.

THE AGRICULTURAL SIGNIFICANCE OF SUNSHINE AS ILLUSTRATED IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau Office San Francisco, Calif., Sept. 4, 1919.]

SYNOPSIS.

Sunshine is important in plant growth because the heat and the light required by all growing plants are supplied by solar radiation. While heat can not entirely replace light in this process, light can in large measure replace heat. The quality and the quantity of the sunlight transmitted to growing plants are both dependent upon atmospheric conditions, as well as upon the season of the year. They vary from place to place and from month to month.

Of the various weather elements, sunshine, directly through radiation, and indirectly through its effect upon air temperatures, influences the distribution of crops. Because it furnishes the required energy for certain chemical activities within growing plants, as well as promotes evaporation from the foliage, abundant sunshine is required of most plants. Partly because of the power of water vapor in removing certain chemically active rays from the sunlight transmitted through the air, humid regions are best adapted for certain crops, and wholly unfitted for other crops.

California is a State of vast size, and shows extreme diversity of topography, soil and climatic conditions. Sunshine varies greatly in quality and in quantity in different parts of the State. Horticulture, the most important branch of California agriculture, is practiced to best advantage in those portions of the State where the amount of sunshine is at a maximum. For all stages of the fruit, from the blossoming of the trees to the sun-curing process of the fruit, abundant sunshine is beneficial.

The sun curing of fruit, which is both a physical and a chemical process, is an important industry in California. Unbroken sunshine and absence of summer rainfall make the interior valleys the deciduous and citrus fruit centers of the United States. The earliest oranges to ripen in the State are those northern grown, a fact partly due to the increased amount of sunshine received during the summer season.

The dehydration of vegetables, a new industry in California, is making rapid progress. The State is well adapted for this, as abundant sunshine favors the growth as well as the curing of vegetables. Beans grow to best advantage along a narrow belt of the coast, largely because diffused rather than direct sunlight is required. Moreover, the plants thrive under humid conditions and frequent fogs, from which they absorb some moisture. Flower and vegetable seeds, on the other hand, require an abundance of sunshine and dry air, and are therefore raised to best advantage in the sheltered valleys.

California merits the appellation, "The Sunshine State," for the abundant sunshine forms the basis of agriculture, the State's principal industry. The agricultural crops of 1918 were valued at $645,000,000.

INTRODUCTION.

Because of the vastness of its size, its varied topography, and the diversity of its climate and its soil, California agriculture shows an epitome of that of the whole United States. This State has samples of every part of the world which permit successful agriculture. An enumeration of California fruits alone is a catalogue of the known fruits of the world, with the exception of those strictly tropical. This is also true of certain individual countries, which in several instances are larger than whole States.

While in most States the crop-growing season is limited to six or seven months in the year, in California the entire year constitutes the agricultural period. Crops are growing and maturing all the time within the State. There is a continuous seedtime and harvest for something, and there is but occasional coincidence with eastern crop periodicity. There are wider differences within its borders than are found in a long sweep of States from the Gulf of Mexico to Canada. In latitude, California extends from 33° north to 42° north, corresponding roughly with that from Charleston, S. C., to Boston, Mass., on the Atlantic coast of the continent. Owing to the proximity of the Pacific Ocean, and the prevailing westerly direction of its winds, the isotherms run north to south, not east to west, as in the interior of the continent. The mean annual temperature ranges from 42° F. to 76° F., while extremes of −21° F. and 134° F. (the highest natural shade temperature recorded anywhere on the earth's surface) have occurred in different parts of the State in the same year. The mean annual precipitation ranges from 2 inches to 113 inches, with extremes at different stations ranging from no rainfall to 154 inches. Altitude above sea level rather than latitude controls the temperature, while altitude together with latitude control the precipitation. The southern and lower portions of the State are drier than the northern and higher portions. Summer and winter are terms synonymous with dry and wet seasons, respectively, rather than with warm and cold seasons. About 90 per cent of the total annual precipitation occurs between October 1 and March 31. Topography is of more importance as a control of climate than is latitude, and the State contains the highest as well as the lowest points in the United States.

Sunshine, the only element of climate here considered, varies greatly in amount from month to month, as well as from county to county. California has been termed "the sunshine State," but the title is not equally merited by all portions of the State. While cyclones control the weather, their transcontinental paths are deflected so far to the north during the summer half-year that the State then enjoys subtropical, rainless conditions. The interior valleys then receive the maximum possible amount of sunshine, and practically cloudless skies sometimes prevail for several successive months. On the other hand, the indraught of cool, westerly winds from off the ocean brings in fog along the coast, which penetrates 10 to 20 miles inland every night, but which is dissipated to some extent during the day. On exposed places like Point Reyes the sun during midsummer sometimes remains invisible on account of fog and low cloud for more than three weeks at a time. Under these varied conditions of cloud and sunshine the State sometimes has the highest and the lowest temperatures in the United States during midsummer.

The climates of California may be roughly classified as (*a*) coast; (*b*) valley (including foothill); and (*c*) mountain.[1] With particular reference to sunshine, these may briefly be described as follows: The coast climate is one of equable temperature, with relatively cool summers and relatively warm winters; abundant rainfall, increasing from the south to the north; humid atmosphere at all times, with much fog and cloud, and hence with deficient sunshine, particularly during the summer half-year. In spite of the almost saturated condition of the atmosphere during the summer, measurable precipitation is then negligible in amount. The valley climate is one of high summer and low winter temperatures, with deficient rainfall in the south, increasing to abundant in the north; extremely dry air and almost unbroken sunshine during the summer; and only a moderate amount of cloudy and rainy days during the winter, with comparative freedom from fogs. The foothill climate, that of places up to 2,500 feet in elevation, differs from the valley climate principally in its smaller ranges of temperature and a slightly higher annual rainfall. The valleys and foothills together form the principal agricultural portions of the State. The mountain climate is one of moderately warm summers and moderately cold winters, abundant precipitation, increasing with altitude up to about 5,000 feet, and abundant sunshine, particularly during the summer half-year.

[1] Cf. W. G. Reed, Climatic provinces of the Pacific coast, *Bull. Am. Geogr. Soc.* (New York), Jan., 1915, **47**; 1-19, 4 figs. (Review, *Science*, Aug. 20, 1915, N. S. 42: 251.)

SUNSHINE AND HORTICULTURE.

Horticulture is the leading agricultural activity in California, and its importance is constantly increasing. Since the terms northern and southern have little climatic and no agricultural application here, northern fruits reach perfection, under proper conditions, at the south, and vice versa. In the words of Prof. E. J. Wickson, of the college of agriculture of the University of California:[2]

> The apple and the orange, fruit kings whose kingdoms lie at opposite borders of the Temperate Zone, so far distant that one may be called semifrigid and the other semitropical, have in California utter disregard for the parallels of latitude, which set metes and bounds upon them in other lands, and flourish side by side, in suitable localities, from San Diego to Shasta.

Moreover, some fruits can be successfully grown through a north-south distance of 500 miles, but can not successfully be carried through a few hundred feet of either less or greater elevation. Occasionally, snow-clad mountains and groves of delicate orange trees are in close juxtaposition laterally, though at different altitudes above the level of the sea.

The meteorological conditions under which fruit growing is most successfully carried on in California are primarily (*a*) abundant sunshine, (*b*) low atmospheric humidity, (*c*) absence of extremely low temperatures, and (*d*) generous soil moisture, largely supplied by artificial irrigation. Through a combination of these conditions, fruits are found to grow to best advantage in the valleys and on the foothills and lower mountains. Because of the deficient sunshine and the excessive humidity fruits are not grown in commercial quantities on the immediate coast. Direct and not diffused sunshine is necessary for ripening some fruits, but still more is needed for their curing and preserving. The excessively low relative humidity of the atmosphere over the interior valleys during the daylight hours of summer permits the penetration through it of an intense sunlight. This results in a maximum physical as well as chemical action on the growing fruit. The physical heating of the plant tissue is promoted, and the evaporation of part of its water is accelerated. In addition, the growth of some microscopic parasites is checked, and certain ripening processes of the fruit are hastened. Favorable comment is often made concerning the absence of certain parasites and the excellent keeping qualities of California fruits. While in a measure this is due to fumigation and the artificial application of germicides, it is also partly due to the beneficial effects of the sunshine to which the maturing fruit is subjected during the long, cloudless summer. The distinctive flavor and the characteristic aroma of California fruit can also be explained in the same way. The extreme dryness of the air promotes evaporation, and hence aids the flow of sap in the trees.

The horticultural year begins with the blossoming of the almond trees in January, an event which marks the advent of spring in California. The period of greatest fruit growth is from May to September. Deciduous fruits are harvested chiefly during the same months; citrus fruits are harvested chiefly from December to June. The rest period in trees and vines is a dry season climatically, not a cold season as in the East. The autumn rains usually begin in October. The character of the autumn, particularly with reference to rainfall, determines in large measure the size and the quality of the fruit crop of the following year. An interesting example of this relation is apparent in the 1919 deciduous fruit crop, which is the largest crop of this kind ever grown in California. During September, 1918, the heaviest rains recorded in a month of September in California during 69 years of record were general throughout the central portions of the State.

That sunshine is of prime importance in fruit growing may be seen from its influence in all stages of the fruit, from blossoming to maturity. During the blossoming period of deciduous fruit trees, principally February to April, inclusive, there is usually enough sunshine each year to produce a satisfactory set of fruit. The winter rains are decreasing in frequency and in amount during this period. While there may be cloudy and rainy days during the blossoming period of any one kind of fruit tree, these conditions are rarely so long continued as to prevent proper pollenation. The temperatures are then so high that bees and other pollen-carrying insects may be expected to fly. After the fruit has set, its early growth is accompanied by longer and longer days, more and more sunshine, with increasing intensity. When the sun reaches its maximum altitude about June 21, cloudless skies occur every day. In the fruit-growing regions it not infrequently happens that 100 per cent of the possible sunshine is received during June. As the chemical qualities of the sun's rays are also probably at a maximum during June and July, all deciduous fruit makes rapid progress toward maturity. (During hot July weather in Iowa the farmers say "It makes the corn grow;" in California the fruit growers say "It puts sugar in the prunes." Cloudless skies usually continue during the harvest of the fruit. That to be consumed as fresh fruit is shipped in express refrigerator cars which move eastward in trainload lots on fast freight time schedules. That which is to be dried is placed upon wooden or paper trays and exposed to the hot sunshine.

THE SUN-CURING PROCESS.

The sun curing of fruit in California is a great industry. The unbroken sunshine and the absence of rain during July, August and September make possible the sun-curing of thousands of tons of fruit every year. The latter consists principally of raisins, prunes, peaches, apricots, pears, and apples.

Raisin grapes are grown chiefly in the San Joaquin Valley, Fresno being the center of the largest and most important raisin district in the United States. Grapes are not considered fit for raisins that do not contain at least 22 per cent of sugar. Before picking, the actual sugar content of the grapes is determined by the use of the sacrometer. If it is below 22 per cent, picking is postponed until that proportion has been reached, which is usually during August. Before the crop is completely harvested, the grapes test from 24 to 26 per cent sugar, which is the proper proportion to make the best quality of raisin.

The fruit is allowed to remain in the sun until all visible portions of the fruit are brown. As soon as this stage is reached the trays are immediately stacked. The berries are still soft, and contain considerable moisture which evaporates slowly in the shade or stack drying process, leaving the fruit in far better condition than if completely cured in the sun. This shade drying takes from two to three weeks, according to the weather. The increased humidity, which is apparent toward the latter part of September and the early part of October, also improves the condition of the stems, allowing the sorting of layers with very little breakage.

[2] E. J. Wickson, "California Fruits," p. 19.

FIG. 1.—A California almond orchard in full bloom. The blossoming of the almond trees in January marks the advent of spring in California.

FIG. 2.—A Santa Clara Valley prune orchard in full bloom. San Jose, the largest city in this valley, ships more prunes in the course of a year than any other city in the United States. The weather conditions prevailing at the time of blossoming and setting of the fruit are of great importance in determining the size and quality of the crop.

FIG. 3.—Blossoming prune trees in the Santa Clara Valley of California.

FIG. 4.—Prunes being sun cured in the Santa Clara Valley of California. This region produces more prunes than any other region of equal size in the world. Because the prunes are sun cured, and not dried in artificial driers by means of artificial heat, Santa Clara Valley prunes have a most delicious flavor, and sell for higher prices than those grown elsewhere.

FIG. 5.—Prunes exposed to the hot sunshine on wooden trays in the Santa Clara Valley of California. Two to three weeks are required to complete the process. Weather conditions are all important at this time. When rain is anticipated the trays are stacked and covered. The official weather forecast is therefore of prime importance, and is eagerly watched for every day.

Prunes, a species of plum, are grown chiefly in the Santa Clara Valley, San Jose being the center of the largest prune district in the United States. The mature prunes are bathed in dilute lye solution, which softens and sterilizes the skin. They are then thoroughly washed and subsequently are spread on trays in the hot sunshine. After a week or two, water is almost entirely evaporated, and the sunshine has turned the red flesh of the prune to a black color, and the juices are largely converted into sugar. Sun-cured prunes have a characteristic flavor, and sell for a higher price than those artificially dried.

Peaches, apricots, pears and apples are grown in many valleys of the State. On maturing, these fruits are subjected to sulphur-dioxide gas, which has a germicidal effect, and also causes a chemical reaction which preserves the flesh of the fruit, and prevents if from turning black.

The sun curing of fruit is thus a physical as well as a chemical process. The intense sunshine, aided by the excessively dry air, promotes the evaporation of superfluous water, and converts the juices into sugar and other solids, of great nutritive value. The compactness of dried fruit and its excellent keeping quality make it one of our most valuable food products. A pound of raisins contains more nutrition than a pound of beef steak, and costs much less.

During the fruit-curing season there is naturally much interest in the weather, for on rare occasions rain falls upon the exposed fruit, doing immense damage. The official weather forecast is therefore eagerly looked for each day. When rain is anticipated, the trays containing the partially cured fruit are stacked and covered until danger of precipitation is past. (The confidence of the fruit grower in the Weather Bureau is well illustrated by the following incident. The writer was temporarily in charge of the local office of the Weather Bureau at San Jose during a part of August, 1919. On the morning of Aug. 28, when several thousand tons of prunes were exposed on trays in the Santa Clara Valley, the sky looked threatening. Within a period of three hours a total of 66 telephone requests for the weather forecast were received, and in addition many persons, including the editor of the evening newspaper, called at the office in person in order to secure the latest available information. The forecast of no damaging rain was fully verified, and the growers were thus saved the labor and expense of stacking the thousands of trays.)

Rain to the amount of 0.25 inch or more will do no damage to the drying fruit provided that sunny, drying weather follows within a day or two. But even a light shower, if followed by several successive days of cloudy and damp weather, will produce mildew and rot, which will damage or even destroy the food value of the fruit. Under ordinary conditions, however, every day during August and nearly every day during September is clear and dry. When every day is sunny, the fruit will be cured in one to three weeks, depending upon the kind and the condition of the fruit. The Weather Bureau offices at Fresno and San Jose are of particular importance during the fruit-curing season.

A new industry, which is destined to grow rapidly, has recently appeared in California. This is the dehydrating of vegetables. Sunshine plays an important part both in the production of the vegetable and in its dehydration. The first experiments on a commercial scale in the dehydration of vegetables were made by a California hop grower about 1915, who saw in the spread of the prohibition movement the extinction of hop growing as a profitable industry. The experiments proved to be so successful that before the close of the World War several hundred tons of dehydrated vegetables had been ordered by the commissary departments of various allied armies. At the present time the United States Department of Agriculture is spending $250,000 in informing the consuming public as to the merits of dehydrated vegetables.

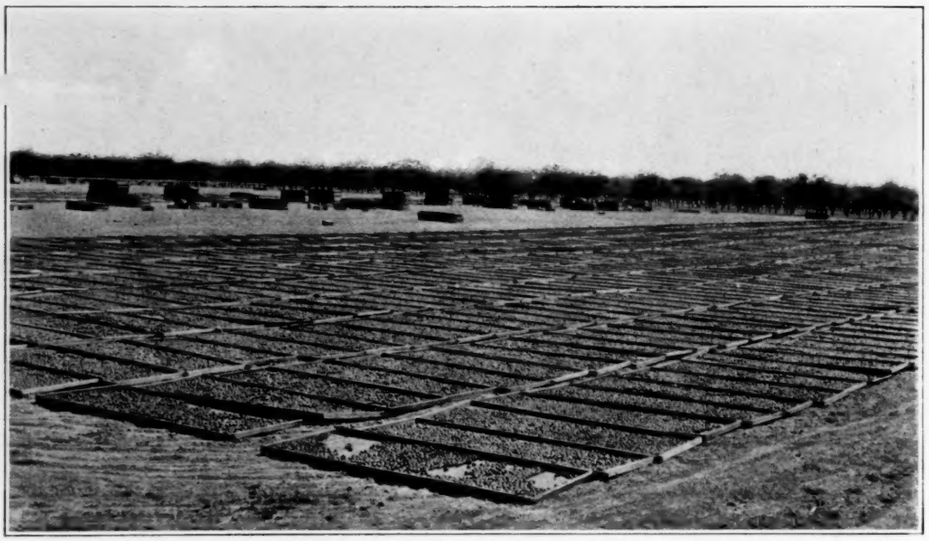
In this process of dehydration the vegetables are dried either in special driers, with ar[illegible] they are sun cured, as is the fruit. The vegetables most commonly dried are potatoes, cabbage, onions, beets, beans, and peas. Through physical and chemical changes the pulp is reduced to a compact and dry mass, which, when properly packed and stored under satisfactory atmospheric conditions, will keep for years. When a housewife wishes to prepare the dehydrated vegetables for use, the dried product is first soaked in water, and then cooked as usual. After a short time it is ready to serve, with a flavor and an aroma as though fresh from the garden.

SUNSHINE AND CITRUS FRUIT.

The importance of sunshine is well illustrated in the growing of oranges, California's most valuable fruit crop. The dark-green foliage of growing orange trees absorbs most of the heat and light received from sunshine, but little of either being lost through reflection. The fruit makes slow but steady progress during the long clear days of summer and autumn, and the principal harvest comes in the winter and spring. Every effort is made by the orange growers to accelerate the maturing of a portion of the early crop in order that oranges may reach the eastern markets in time to catch the Christmas trade, and, if possible, the Thanksgiving trade. In this attempt to reach an early market, when the demand is high and when fancy prices are obtained, there is intense rivalry between the orange growers of northern and of southern California. Primarily because of the greater amount of sunshine received during the summer growing season, the northern California groves have produced the first carload lot of oranges during the autumn of each of several past years. This is an eagerly sought honor, and the record of northern California is all the more impressive when it is realized that southern California produces the great bulk of the orange crop, and has a warmer and more equable climate.

SUNSHINE AND VEGETABLES.

Another interesting example of the influence of sunshine, or rather the lack of it, is apparent in the production of the greater part of a large bean crop along a narrow strip of coast, extending principally from San Francisco southward to the Mexican border. The climate of this region is characterized by equable temperatures, increasing from north to south; relatively cool summers and relatively warm winters; moderate rainfall, increasing from south to north, but limited almost entirely to the winter months; prevailing westerly winds; and a humid atmosphere, with frequent fogs and overcast skies, particularly during the summer. While the soil conditions of this region are not greatly unlike those of other portions of the State, this narrow belt produces beans of many varieties, the bulk of the State's great bean crop. It appears that the bean plants extract some moisture from the humid atmosphere and the dense fogs, though little or no precipitation is recorded during the growing season. The sunshine received is that which has traversed a humid and cloudy atmosphere. The light transmitted to the plants, therefore, is rich in the qualities characteristic of the middle portion of the solar spectrum, but deficient in those qualities



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characteristic of rays of either end of the spectrum. The bean crop is harvested principally in the autumn, which brings the maximum amount of sunshine this region receives during any season of the year. The crop is sun-cured, and the dried beans are separated from the pods by means of thrashing.

Partly because of differences in the amounts of sunshine received, sugar beets grown for seed are cultivated in one region, while those grown for the beets are produced by another portion of the State. (Previous to 1915 most of the sugar-beet seed was imported from Germany.) Vegetables are grown in commercial quantities principally in the humid valleys bordering the coast. A very large crop of potatoes is grown in the delta district near the mouth of the Sacramento River. In this restricted region summer temperatures are not so high as in the more interior valleys, and evaporation is relatively small. Sunshine is reduced in amount, and of a peculiar quality adapted for vegetable growth.

The growing of flower and vegetable seeds is an important part of California agriculture. A considerable proportion of the flower and vegetable seeds of the United States is grown in this State. For some particular varieties, practically all of the seed produced in the United States comes from California. In general, much sunshine and a minimum of atmospheric moisture are the conditions best suited for seed production. These conditions are particularly desired during the summer harvest season, when the crops are sun cured, and the seeds are extracted by means of thrashing machinery.

That the people of California are not unmindful of the significance of sunshine as a resource is evident from the great frequency with which the word sun enters into their vocabulary. In this "Sunshine State" we have "Sunkist Oranges," "Sun-Maid Raisins," and "Sun-Sweet Prunes." Most of these are shipped eastward over the "Sunset Route." As it is recognized that sunshine is the best natural germicide, enterprising real estate dealers advertise "Sunlit Homes." Life is largely in the open. In southern California many people practically live out of doors and are known as "Sun-Worshipers." Both in attracting tourists and in aiding agriculture, sunshine is one of California's most valuable natural resources.

PROJECT FOR LOCAL FORECAST STUDIES.[1]

By R. H. WEIGHTMAN, Meteorologist.

Weather not only affects persons in all walks of life, but is a controlling influence in every phase of human endeavor. On the condition of the meteorological elements depends the convenience and success with which our daily tasks and pleasures are accomplished—from the child who is laying the foundation of his educational structure to the business and professional man engaged in the prosecution of useful pursuits. The fact that weather and its effects are of universal interest is as true to-day as in the past. As a natural and logical sequence to this universal and time-honored interest experienced by mankind as a whole, weather changes have been impressed on his attention, thus laying the foundation for the many dictums and proverbs, associated with nature's signs as revealed in the clouds, sunsets, the moon, and in the habits and actions of animals and plants that we have to-day. Some of these sayings have a more or less sound physical basis, while others are grounded in fancy and superstition. Nevertheless, they have been handed down from generation to generation without distinction, until they have gained an entirely false significance in the public mind, especially among those who have not had the occasion and inclination to actually compare the saying on the one hand with the occurrence of the meteorological phenomena on the other.

As the science of foretelling the weather has progressed, meteorologists have gradually discarded the consideration of local signs and influences as indices of subsequent weather in favor of the surer, sounder, and more accurate indications of the weather charts which depict simultaneous conditions over wide areas. In fact, they have gone so far in this direction that, at the present time, scant attention is paid to purely local conditions in the preparation of forecasts, although any one familiar with local signs must admit that, at times at least, they are exceedingly valuable and important.

In 1883 a treatise on "Weather Proverbs" was published by H. C. Dunwoody, and in 1903 Prof. Garriott presented his bulletin on "Weather Folk Lore and Local Weather Signs" which brought together many of these old dictums and sayings. Later, Prof. Humphreys, in an article entitled "Some Weather Proverbs and their Justification" which appeared in the May, 1911, issue of Popular Science Monthly gave some interesting and instructive views on the physical reasons and principles underlying some of them.

A table showing the probable character of the weather based on the barometric pressure and wind direction is given in the bulletin by Prof. Garriott, while in the MONTHLY WEATHER REVIEW numerous references to clouds as indicators of the subsequent occurrence of precipitation have appeared from time to time. Officials of the Weather Bureau have prepared tables showing the relation of temperature, humidity, wind direction, pressure, pressure change, clouds, etc., to subsequent weather but, from the fact that results obtained by these methods were not so reliable as those based on the daily weather charts, such schemes have not been widely appreciated, nor have they been very much used.

Although as a rule local conditions play a rather unimportant rôle in the preparation of the general forecasts, yet there are times when the results to be expected from the weather map are extremely uncertain and doubtful, and at such times the forecaster grasps at any indication that may give him a clue to what weather may be expected to follow. Only recently Maj. E. H. Bowie proposed that the relation or bearing of all the weather elements, or combinations of them, be brought together into a single index or probability number, the influence of the different elements being proportionally weighted and, provided such a plan prove feasible, that such information be included in the telegraphic report of observations. Such a scheme would be on a strictly statistical basis and would not involve in any way the personal equation of the observer. It has been contended that such a scheme has advantages in mountain and coastal regions but that it would not be suitable for use in level areas with continental climates where the local signs that might be considered as indications of local weather changes are merely the usual results of well-known meteorological laws. While the latter is true, it is patent that, as long as conditions undergo changes, the question is how far

[1] Read by title, American Meteorological Society, Washington, D. C., Apr. 22, 1920.

ahead are the incipient stages of these changes manifested in some one or more of the meteorological elements, whether it be in their absolute values, in the changes in them, or in a combination of the two. We know, for example, that changes from an entirely cloudless sky to a rain condition do not come about suddenly. There is some manifestation either in the amount of cloud, in a change in its type or height, in a change in pressure, in a shift in the wind, etc., and it is these preliminary signs that, it is believed, can be used to advantage for giving some clue to subsequent conditions. Of course, the shorter the interval between the time the forecast is made and the period covered by the forecast, the more certain will be the prediction but it seems reasonable that we may expect in many cases to find some indication at 8 a. m. for example of the incipient stage of the condition we may expect to occur between 8 p. m., and the succeeding 8 a. m. certainly at least the local conditions at 8 a. m. will give a valuable indication of the conditions to be expected in the succeeding 12 hours.

Attention has been given to the problem in Sweden by Bruno Rolf in a paper entitled "Probabilité et Prognostics des Pluies d'été" (Probability and forecasting of summer rains), published at Upsala in 1917, in which he shows the possibility of the development of such a system. He first arranges the data at Stockholm, covering a period of 59 years, by groups according to pressures, temperature departures, relative humidities, vapor pressures, directions of wind, cloudiness, and then by two and three element combinations, taking conditions at the 9 p. m. observation as the basis for prediction and comparing the indications with the precipitation that occurred during the 24 hours beginning at 8 a. m. of the succeeding day. Graphs are given showing the probability for each element and also for the two-element and three-element combinations. He shows that low pressure, low temperature, high relative humidity, high vapor pressure, and high values for cloudiness and the south wind are favorable for rain, while the opposite state of these elements and the west wind are unfavorable. For pressure, and combinations of pressure with other elements, the probability has the greatest values and the greatest range, and for vapor pressure, the least.

Although 59 years' observations were used, the author states that in dividing the material into groups according to the different values of three elements, the limit of possible division is reached for the reason that subdivision with regard to a fourth is too little provided with forms. Since it is found that the curves representing the probability of rain as a function of the pressure with different values of the other elements show more regularity and greater range within the limits of probability, 0 and 1, than curves giving the probability in terms of other arguments under different conditions of pressure, he overcomes the difficulty of further subdivision by developing a mathematical expression to represent this type of curves which he calls barombrometric curves, the terms of which are deduced from the data. This formula deals with the probability of rain based on three elements, pressure, cloudiness, and relative humidity, and the author states that other elements may be added by correcting or modifying the constants of the formula through the consideration of other factors. He considers only the state of the different elements, but believes that the scheme can be improved by considering also their changes. He has verified the operation of his scheme and finds that 44 per cent of the changes—whether from fair to rain, or rain to fair—are correctly forecast, while a verification of 80 per cent was obtained when conditions did not change, giving a combined percentage for all cases of 68 per cent. By considering the wind direction in addition, this verification was increased to 69 per cent. The author concludes as follows:

> The method of prediction, the application of which we have attempted, although it has led to appreciable results, has not yet been sufficiently elaborated in detail that one may affirm that it could be substituted for the synoptic charts. But *a priori* nothing opposes such an assertion. * * * In any case it can be affirmed that we have furnished a useful complement to the synoptic charts. * * * The salient point here is the simultaneous consideration of several elements; the attempts made thus far in taking account of only one have not, it must be admitted, led to very satisfactory results.

Another interesting paper by Geo. F. McEwen and Ellis L. Michael entitled "The functional relation of one variable to each of a number of correlated variables determined by a method of successive approximations to group averages," has been published recently in this country, and while it does not treat our problem directly, may possibly be susceptible of adaptation to it. The method of multiple or partial correlation has also been considered. The problem is a decidedly complex and difficult one for the reason that each, if not all, of the independent variables, namely, the different meteorological elements, will have quite different probability values depending on the values of the other elements and these relations, it is believed, will not be linear. It would seem, therefore, that they will have to be considered in combinations and the different values of these combinations of two or more elements will have to be introduced into the expression giving the form of the functional relation, much the same as was done by Rolf.

It is believed that a study of this character based on local indications is more applicable to short-range predictions (less than 12 hours, for instance), which are of such importance in connection with aviation work; and that results thus obtained will be sufficiently valuable to warrant the telegraphing of probability indices or numbers with the regular observations, as has been advocated by Maj. Bowie. However, the matter is still in the investigational stage and it is premature to come to any definite conclusions at this time.

It would seem, however, that a profitable, and in the United States at least, a rather unexplored field of investigation is open to local officials of the Weather Bureau in studying local data available at the time of the morning observation with a view to answering some of the numerous inquiries made by the public concerning weather conditions for the afternoon or evening, as for example: "Will it be cloudy this afternoon?" "Will it rain before noon?" "Will there be a thunderstorm?" "Will the snowfall be heavy or light?" etc., *ad infinitum*.

Considerable work has been done in the prediction of minimum temperatures from hygrometric observations by Prof. J. Warren Smith and others, some work has been done at the New York Weather Bureau office on heavy snowfalls, and undoubtedly considerable other work of a similar character, which has not come to the attention of the writer, has been carried out by other officials of the Bureau.

The methods of statistics afford a direct and efficient means of attacking the problem of making short-range predictions, a careful investigation of which will materially aid in stimulating and promoting the development of a more complete knowledge of the physical changes and processes that control atmospheric phenomena.

MACKEREL SKY AS A PROGNOSTIC OF PRECIPITATION.

By H. H. MARTIN, Observer.

[Weather Bureau, Columbus, Ohio, May 15, 1919.]

While compiling other data for investigation I have taken note of the occasional record of "mackerel sky" at the Columbus, Ohio, station. Of the 17 records made, it has been found that 10 were followed by precipitation within 12 hours, 15 within 24 hours, and 17 (all) within 48 hours. As will be agreed, the occurrence of "mackerel sky" is evidently of great prognostic value. However, the records of this formation are sparse and the value 13 does not, in my opinion, represent anything like the total number of times this cloud has been observed in the past 10 years.

I believe that this cloud formation is of sufficient importance to justify more complete records, and that it should be recorded, together with the time, direction from which moving, and where densest, whenever observed. "Mackerel sky" is usually of such short duration that an observer must be on the alert to note every occurrence. I believe that if such records were made, however, the results would be of greater value than any other cloud record in the forecast of precipitation.

ON THE USE OF CIRRUS IN THE FORECASTING OF WEATHER.

By G. REBOUL and L. DUNOYER.

[Abstracted from *Comptes Rendus*, Mar. 22, 1920, pp. 744-747.]

It is a well-known fact that the distribution of cloudiness in advance of a low pressure area can be used for local forecasting. This paper presents the deductions from observations made at Malzéville, France, regarding the use of cirrus for this purpose. The rules deduced and the factors of certainty are presented here:

1. *The appearance of cirrus in a certain direction indicates the existence of a depression in that vicinity.* Certainty: In summer, 0.92; in winter, 0.94; when cirri are from west, 0.96; from the east, 0.81.

2. *The direction of movement of cirrus indicates the direction in which the depression is to be found.* Certainty: In summer, 0.84; in winter, 0.81; when cirri are from west, 0.91; from the east, 0.57.

3. *The direction of movement of cirrus indicates the direction of motion of the center of the depression.* Certainty: In summer, 0.67; in winter, 0.60; when cirri are from west, 0.76; from the east, 0.43.

4. *Cirri of high speed foretell a rapid motion of the center.* Certainty: January to October, 1916, 0.72; July, 1918, to July, 1919, 0.68.

5. *Abundant cirrus indicates, on occasions when the depression is in the vicinity of the place of observation, where it is intense.* Certainty. 0.77.

The warning is made that too much confidence should not be placed in cirrus as precepts for forecasting, and that these rules are applicable only to LOWS in the north or east of France and in cases where the coefficient of certainty is very large.—*C. L. M.*

NOTE.—These conditions, of course, are those with which the French have to contend, but some of the above rules would not be applicable in America. The reason is that barometric depressions in America travel much more rapidly than those of Europe, and it is therefore possible that the direction of motion of cirri indicate the radial motion from the center of the storm; on the other hand, in America, the center of the cyclone moves forward much more rapidly, so that the direction of motion of cirri represent the direction of motion of the storm, but not the location of the center, as is implied in (2) above.—*C. F. B.*

THE SNOWFALL IN THE WESTERN STATES, WINTER OF 1919-20.

[Abstracted from Section Directors' Reports by A. J. Henry.]

In general the winter of 1919–20 was one of greatly reduced snowfall as compared with the normal. The distribution was abnormal in that rather heavy snow fell in the early part of the season, the greater portion of which disappeared before January 1, 1920. The fall of both January and February was much below normal and the outlook at the end of February was distinctly disappointing. The snowfall of March was fairly heavy in practically all of the Western States, but coming so late in the season it will not make up the deficiency of the midwinter months.

The most-favored districts appear to be southwestern Colorado and portions of Wyoming. Meteorologist A. H. Thiessen, in charge Climatological Service of Colorado, concludes that the flow of the Grand and Gunnison Rivers will be more than normal and that that of the Yampa, White, and San Juan Rivers will be considerably above the normal, thus giving an increased flow in the Colorado which he estimates at 30 per cent.

Snowfall in the Columbia watershed was deficient, particularly in the Coast States. Meteorologist E. L. Wells, of Portland, Oreg., concludes that with moderate, seasonable temperatures during May the run-off from the Snake River will be nearly normal and comparatively early and that nearly the usual volume of flow will come out of the Columbia.

THE DROUGHT IN CALIFORNIA.

By ANDREW H. PALMER, Meteorologist.

[Weather Bureau Office, San Francisco, Calif., April, 1920.]

In California the year is divided into well-defined wet and dry seasons. Nearly all of the precipitation occurs during the winter half-year. The character of the rainy season, therefore, determines the prosperity of agriculture, which is largely dependent upon artificial irrigation. Hydroelectricity is largely used for pumping the irrigation water.

Because of abnormally deficient precipitation during the rainy season 1919–20, the central and northern portions of California face a serious problem during the summer of 1920. As the three preceding rainy seasons have also brought deficient precipitation, and the season just ended the least in many years, the natural reservoirs are largely depleted. An inevitable shortage of water will occur during 1920 in central and northern California. Generous rains in March assured the maturing of winter growing grains and grasses, and revived fruit trees. But summer growing crops, particularly rice, and general field crops, as well as deciduous fruit, will require much more water than now appears to be available in the partially filled reservoirs. Mr. H. D. Butler, State power Administrator, estimates that the deficient rainfall of the past season will cause a loss of $22,000,000 in the Sacramento Valley alone during the summer of 1920.

The public utility commission in California is known as the Railroad Commission of the State of California. It has authority over hydroelectric power companies, and also over those water distributing companies which are classed as public utilities. Recognizing the gravity of the situation, and in the hope of preventing costly litigation, the railroad commission has organized a body called the Emergency Water Conservation Conference, which includes in its membership representatives of all the State and Federal agencies concerned with the water problem. It includes representatives of the State railroad commission, State water commission, State department of agriculture, State university, State department of engineering, United States Geological Survey, United States Weather Bureau, United States Bureau of Irrigation Investigations, and the United States Army. This conference held many meetings during March and April. Through an educational campaign the public was informed of the pending water shortage, and urgent recommendations were made for the conservation of water.

The larger water users of the Sacramento Valley voluntarily signed an agreement turning over to the conference authority to control and to apportion the available water of that valley during the summer of 1920. These water users voluntarily assessed themselves on an acreage basis an amount which will give the conference about $30,000 for administrative purposes in dealing with the water problem. As the hydroelectric power will be insufficient for pumping irrigation water, steam pumping plants are at present being installed in many places in the valley. Mr. Paul Bailey, chief engineer, has been engaged by the conference to act as water administrator, and he will spend a large portion of the summer in the field in connection with his duties.

During the summer of 1919 the Sacramento River reached unprecedented low stages. Navigation, which under normal conditions is possible to Red Bluff, was possible only as far as the city of Sacramento. While the Sacramento River is usually at a high stage during the spring months, at this writing (Apr. 13.) it is so low that it appears that the river will establish a new low record stage before the close of the summer. Certain results of the recent low stages of the river are of peculiar interest.

Under normal conditions, the flow in the delta region, just before the river enters San Francisco Bay, is sufficient to cause the water to remain fresh. However, during the recent low water the flow has been so scanty that the salt water from San Francisco Bay has encroached upon the rich agricultural lands of the delta region, and irreparable harm will follow if the salt water remains long enough to saturate the lands adjacent.

Furthermore, certain industries, including the California-Hawaiian Sugar & Refining Co. and the Southern Pacific Railroad, have built piers at various places in the delta region. These piers rest on wooden piles. In designing these structures it was expected that only fresh water would ever surround these. Salt water would be destructive to these untreated piles if the contact were of long duration. At present the salt water is steadily passing farther and farther up the delta, apparently to remain until the next rainy season. If that occurs, many thousands of dollars of damage will result. Property owners in the delta region have gone to the courts of law and are seeking an injunction against the taking of water from the upper Sacramento River while the low water continues in the delta region. The conference, referred to above, hopes to save the various interests costly and long-drawn out litigation. The importance of rainfall, and the need of wide margins of safety in engineering projects dependent upon it are emphasized in the present situation.

"SNOWBALL" HAIL AT TOPEKA, KANS., MARCH 3, 1920.

By S. D. FLORA, Meteorologist.

[Weather Bureau Office, Topeka, Kans., Mar. 12, 1920.]

Thunderstorms occurred in connection with the passage of an area of low pressure which was central over Dodge City on the morning of the 3d and over St. Louis on the morning of the 4th.

The wind at Topeka during the afternoon blew first from the southeast, then from the east, and later from the northeast at the rate of 8 to 12 miles and hour, with the barometer falling steadily and rather rapidly, occasional sprinkles of rain, the temperatures ranging from 46° to 50° F.

A single loud peal of thunder, the first in several months time, was heard at 4:48 p. m., coming from a dark, threatening cloud in the western sky. At 5:08 p. m. the wind shifted abruptly from northeast to northwest and within 10 minutes had increased to 25 miles an hour; and simultaneously the barometer began a rapid rise. The western sky in the meantime became darker and more threatening. Occasional sprinkles of rain continued to fall. The temperature which was 49° when the wind first shifted, fell rapidly, reaching 34° by 6 p. m.

At 6:27 p. m., following several violent peals of thunder, there suddenly began a fall of what first seemed to be small balls of ice from one-fourth to one-half inch in diameter, which almost covered the ground within the space of 60 seconds. This fall lasted for about 5 minutes. the balls striking objects with the velocity of hail stones and seldom breaking from the impact. Rain was mixed with them somewhat, as it is often mixed with sleet, and, as the temperature was quite close to freezing, the rain froze to limbs of trees and wires catching the balls as they fell so that in a short time trolley wires and telephone wires were soon coated with this mixture of ice and snow, or ice balls, making it very difficult to move street cars and causing much trouble with telegraph and long-distance telephone lines by bringing them down.

A close examination of these ice or snow balls showed them to resemble nothing so much in structure as the compact snow balls—the ones as large as base balls—that boys often make from slushy snow by squeezing and working it. They were fully as hard as hail stones, but lacked the concentric layers of the latter. Within a few minutes after they began to fall the ground was white from them and some that fell on sheltered parts of paved streets and roofs were still there the next morning, frozen in with the ice formed by the rain and sleet, which fell at intervals throught the rest of the evening.

DISCUSSION.

The snowballs, obviously, were hailstones formed by the usual back and forth excursions between higher and lower levels. In the present case, however, the lower levels contained, presumably, only partially melted snow, or snow and rain mixed, and not rain alone. Hailstones formed under these conditions doubtless would be compact, but would not show well-defined alternate layers of clear ice and compact snow—only more or less compact snow throughout. Rain unmixed with snow seems essential to the formation of the layers of clear ice.— *W. J Humphreys.*

HAILSTORM OF MARCH 3, 1920, AT BROKEN ARROW, OKLA.

By JAMES W. ARNOLD.

[Weather Bureau, Broken Arrow, Okla., Mar. 12, 1920.]

On the afternoon of March 3, 1920, a thunderstorm, attended by considerable fall of hail, occurred at this station. The observer studied the size, shape, and composition of the hailstones during the first fall of hail and found many interesting things. The size varied, the average being about one-half inch. The peculiar thing noticed was the shape and composition. About eight-tenths of the hail that fell had a perfect conical shape. They were composed, for the most part of white ice, but most of them had planes, parallel to the base of the cone, of clear ice. These planes were probably one-eighth inch thick and their edges were clear cut and distinctly outlined. These planes of clear ice had no fixed position in the cone nor were there any certain number found in each stone. Some had no planes (these were few), others one, and others two and three. None were found with more than three planes. I remember one particular hailstone that had a one-eighth inch base of clear ice while the rest of the cone was of white ice. These conical-shaped stones were hard.

The other two-tenths were round and in some cases elliptical. And one or two were found which tended to have a conical shape. These round stones were soft and easily crushed with the fingers. Those that hit any hard object would be shattered. Upon examining these they appeared to have a crazy quilt design. When they were crushed in the hand, they broke into elongated shafts or needles of ice, from one-fourth to three-fourths inch long. One of these stones that I crushed broke through in the middle and I could see the conical shape but much distorted.

I was unable to observe the second fall of hail but from what I could see they evidently were much smaller on the average than the first hail. These were soft, as they went to pieces on hitting the roofs of buildings.

The weather in the morning and early afternoon was mild and humid, with a strong south wind (15.8 m/s at 4 p. m.), and the sky partly cloudy. The noon cloud observation was 0.8 Cu. from S., and that at 3 p. m., 0.5 Cu. from south, 0.1 A. Cu. from west, and few Ci. Cu. from west. The morning kite flight showed at 1,000 meters altitude a south wind of 26.6 m/s, temperature 9.2° C., relative humidity 82. At 3 p. m. winds up to 1,000 meters were a little west of south, and lighter. The surface conditions at noon were, temperature 18.9° C., dew point 12.4° C., and at 3 p. m., temperature 22.2° C., dew point 13.0° C.

The thunderstorm developed rapidly in the southwest and the first thunder was heard at 3:37 p. m., about two minutes after it had started to rain at the station. The thunderstorm, I should judge, was about 10 or 12 miles away, which would put it over the Arkansas River. The first rain came from Cu. Nb., which broke away from the center of the storm and passed rapidly over the vicinity of the station. This rain continued intermittently until 4:03 p. m., when the first hail fell. The hail fell in showers, a hard shower of hail being followed by a let-up for about a minute. The first hail ended at 4:10 p. m. along with the rain. Rain began again at 4:30 p. m and rain and hail at 4:37 p. m., ending at 4:48 p. m.

TORNADO IN SOUTHWESTERN MISSOURI, MARCH 11, 1920.

By THE ASSOCIATED PRESS.

[Report from Branson, Mo.]

A tornado yesterday (Mar. 11) in southwest Missouri killed at least 13 persons, injured a number of others, and did property damage as yet unestimated. Every creek and river of the Ozark Hills region to-day was reported either overflowing or running bank full from the torrential rains that preceded and followed the tornado. * * *

Observers agreed to-day that one tornado instead of two swept the affected districts. Apparently it struck first at Nevada, Mo., where three persons were killed and property damaged $100,000 or more. Lifting, it swept above four counties before it descended and spent its strength in a rush through Taney County and the Turkey Creek Valley, with a toll of 10 additional lives.[1]

[1] For discussion of general weather conditions, see pp. 173-174.

NOTES, ABSTRACTS, AND REVIEWS.

ON THE RELATION BETWEEN THE MOVEMENTS AND THE TEMPERATURES OF THE UPPER ATMOSPHERE.

By V. BJERKNES.

[Abstracted from Comptes Rendus, Paris Academy of Sciences, vol. 170, pp. 604-606, Mar. 8, 1920.]

That the temperature of the lower layers of the atmosphere decreases from the Equator toward the poles is well known, as is also the cause of this decrease and its relation to the winds of the planetary circulation. Aerological investigations have disclosed the fact, however, that the temperature of the upper strata of the atmosphere increases from the Equator toward the poles.

That this latter phenomenon is a necessary consequence of the surface conditions may be shown by considering the earth and its atmosphere as one system, symmetrical with respect to the axis of the earth, around which the whole system rotates. From the well-known differential equations for the equipotential surfaces as modified by centrifugal force, it follows that in a stratum of air which has the same angular velocity as has the earth, the isobaric surfaces will coincide with "level" surfaces parallel to the surface of the earth; while if the angular velocity of the stratum be greater, these surfaces will not be parallel to the surface of the earth but will be more flattened along their polar diameters.

With the exception of a relatively thin intertropical zone, the westerly winds dominate the lower layers of the atmosphere, and hence in these layers the isobaric surfaces are ellipsoids which are more eccentric than the "level" surfaces. Now, as Laplace showed,[1] the atmosphere, assumed to be a fluid and limited by an upper boundary similar to the upper surface of the ocean, extends up to a certain lenticular surface symmetrical with respect to the polar axis of the earth and having an equatorial diameter of 6.6 that of the earth and a polar diameter of 4.4 that of the earth; if, as more recent investigations indicate, the atmosphere has no such limiting fluid surface, but extends out indefinitely beyond the point where attraction and centrifugal force become equal, then the isobaric surfaces approach the practically spherical form due to attraction alone; but in either case the upper air will move under the influence of the friction of the westerly winds of high latitudes and of the easterly winds of tropical regions, the latter exerting the same moment because of their greater distance from the terrestrial axis but relative thinness, the resultant being a movement of the upper air as a solid body with the angular velocity of the earth, so that the rotation of the earth itself can not be altered except by outside influences. Hence it is seen that the exaggerated ellipticities of the lower isobaric surfaces do not continue to extreme heights, but are gradually reduced.

As a consequence, it is at once evident from a diagram that near the surface of the earth the thickness of the stratum between two isobaric surfaces is greater at the Equator than at the poles; but in the upper air, greater at the poles than at the Equator. This thickness, of course, must vary as the specific volume, or as the temperature, of the air. Hence, from the observed wind movements alone, we are led to infer that the surface temperature must increase from poles to equator; but, further, *we must also infer that at sufficiently great heights the temperature increases from Equator to poles.*[2]—*E. W. W.*

[1] See Hann, *Lehrbuch*, 3d ed., p. 2; Milham, *Meteorology*, p. 20; MONTHLY WEATHER REVIEW, 47, 452, 1919.

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THE ULTRA ATMOSPHERES.

By T. C. CHAMBERLIN.

[Abstracted from "The Origin of the Earth," University of Chicago Press, 1916, pp. 10-37.]

The constitution of gases is a matter of great importance to meteorology and to cosmogony. Because of the rapid progress which has been made in our knowledge since the time of Laplace, the works of the latter on the atmospheres of the planets, including that of the earth, and on cosmogony, need revision.

The sun, by virtue of its superior attraction, rules the whole space of the solar system; there is merely reserved a small spheroid about each planet in which the attraction of the latter predominates. This "sphere of control" of the earth is a spheroid of three unequal axes, the minimum of which is about 1,000,000 kilometers long and the maximum of which is about 1,500,000 kilometers long. A mass projected into the field of force within this spheroid will describe an ellipse, parabola, or hyperbola (returning to the earth in the first case), according to the velocity with which projected.

The gravity of the earth, as evidenced by the sphere of control, is the holding power of the earth so far as an atmosphere is concerned; the extent and distribution of the atmosphere will depend upon the motions of the individual molecules composing it. The motions and collisions of gaseous molecules can be treated by the methods of statistics and probabilities; and it is easily shown that at times the speeds of certain proportions of the molecules will rise above the mean velocity to given higher and higher velocities up to a theoretically infinite speed for a vanishingly small number of molecules.

The collisional zone.—No matter how great a velocity a molecule may acquire in the lower atmosphere, or how often it may do so, it can only have its motion damped again by plunging into the surrounding multitudes of molecules; in these lower levels the paths of individual molecules are very short and consequently practically straight. Higher up, where the density of the air is less and the molecules sparser, the paths between collisions become longer and slight curvatures begin to appear in response to the forces arising from the earth's attraction.

The krenal zone.—Still higher up, where the molecules are widely scattered, the curvatures grow more pronounced. When the scattered condition becomes still greater, the earth's gravity may stop the outward flight

[2] It would seem that other factors also enter into bringing about this condition. See W. J. Humphreys, "The coldest air covers the warmest earth," in *A Bundle of Meteorological Paradoxes*, Jour. Wash. Acad. Sci., 10, 153-171, 1920 (abstracted in MONTHLY WEATHER REVIEW, 47, 876, 1919). For the probable movements of the *individual molecules* in the extreme upper regions, see T. C. Chamberlin, *Origin of the Earth*, Chicago, 1916, pp. 10-37.—*E. W. W.*

of some molecules, that have rebounded outward, before the next collision takes place, and turn them back on elliptical curves toward the earth. When, with still further ascent, the air grows attenuated enough, these outward flights and returns without collision come to be the dominant feature. The whole summit of the atmosphere is a mass of vaulting molecules, describing loops of all forms, dimensions, and directions. This zone extends from the collisional zone to the outer limit of the sphere of control; some of the vaulting molecules will reach the limit of the sphere, some will go beyond, but the greater multitude will fall short by various degrees. It is wise to emphasize the extremely scattered state of the krenal molecules, especially in the outermost part of the zone, but it is an error to ignore their existence or their importance for many problems. The krenal zone, because of its extreme attenuation, may be called an ultra atmosphere.

The orbital zone.—Collisions are certain to take place in the krenal zone, and by the laws of probabilities the rebounds will in some cases be such that the molecules will then move more or less parallel to the surface of the earth, and a certain proportion of these will have velocities such as to carry them into stable orbits about the earth, in which they will circulate indefinitely until by chance another collision is suffered. An orbital ultra-atmosphere is thus established in the outer portion of the sphere of control; evidently such a condition can not exist in the collisional zone nor in the denser parts of the krenal zone.

A vaulting molecule endowed with the parabolic velocity will, if suffering no collision, go out of the sphere of control and enter into an orbit about the sun; but collisions suffered by orbital molecules may so modify the orbits as to send some of these molecules out of the sphere also, and these modifications may be brought about by a series of successive, relatively insignificant, changes in the orbits. Molecules lost to the earth in the latter way must again pass through the point of collision and in so doing may eventually be captured again by another fortuitous collision; furthermore, the krenal and orbital phases of the solar atmosphere envelop the atmospheres of all the planets; the earth may gain molecules which never before belonged to it, by collisions between solar molecules and molecules of the ultra atmosphere through which they are passing. An equilibrium tends to be established between the ultra-atmospheres of the planets and the sun, for if one becomes more plethoric than is concordant with its relations to the other, it will feed more into the leaner than it will gain from the leaner.

Serious corrections are thus necessary to the current ideas as to the origin, retention, and loss of planetary atmospheres as set forth by Stoney.[1]—*E. W. W.*

ON THE TEMPERATURE OF THE UPPER STRATA OF THE ATMOSPHERE.

By V. BJERKNES.

[Abstracted from Comptes Rendus, Paris Academy, vol. 170, pp. 747-750, Mar. 22, 1920.]

Upon passing from the troposphere into the stratosphere there is encountered an inversion of temperature, and air movements which are very feeble relative to the surface of the earth; it is easy to find the differential equation of such a surface of discontinuity at which the density of the air and the angular velocity around the axis of the earth both change suddenly. This equation shows that if the density changes, but not the velocity, the surface will coincide with an isobaric surface. In the case of the tropopause, the density of the lower layer is greater than that of the upper; and the angular velocity of the stratosphere does not differ greatly from that of the earth, while that of the upper strata of the troposphere is much greater except in a narrow zone on each side of the Equator and possibly at the poles; hence it comes about that the surface of separation is more flattened along the polar diameter than are the isobaric surfaces of the troposphere, these latter in turn being more flattened than the "level" surfaces, and therefore the tropopause is found at a higher level near the Equator than near the poles.

Similarly, it is easily seen that the angular velocity of the air in a cyclone is greater, and that of the air in an anticyclone is less, than the component of the angular velocity of the earth about the same axis; cyclones and anticyclones being local formations not extending into the stratosphere, it follows[1] that in the highest parts of a cyclone the temperatures will be greater, and in the highest regions of an anticyclone they will be lower, than elsewhere at the same levels; and from the equation referred to above it appears that the tropopause has a depression above a cyclone and an elevation above an anticyclone; these elevations and depressions are not the causes of the formations, but merely the effects of the air movements.[2]—*E. W. W.*

WINDS AND TEMPERATURE GRADIENTS IN THE STRATOSPHERE.[1]

By G. M. B. DOBSON.

[Abstracted from Quar. Jour. Roy. Met'l. Soc., Jan., 1920, 46; 54-64.]

Some years ago observations by "ballon-sondes" showed that while the troposphere is colder in cyclones than in anticyclones, the reverse is the case in the stratosphere, and it was pointed out that as a consequence of this the wind velocity must be reduced in the lower part of the stratosphere. Data obtained from 70 cases where "ballons-sondes" had been followed by theodolites to heights well within the stratosphere and had given satisfactory temperature and pressure records were plotted, *heights being referred to the tropopause, thus causing the elimination of effects due to the variation in the height of the base of the stratosphere above mean sea level.* The resulting diagrams show very clearly that which is not shown when heights are referred to mean sea level, viz, the remarkable suddenness of the changes which take place at the tropopause.

The wind velocity within the troposphere increases with height at a rate roughly inversely proportional to the density, i. e., at a rate which would occur if the pressure gradient remained constant. It may be taken as a general rule that whenever the velocity is fairly large, say, 15 m/s, in the troposphere, it almost invariably decreases very suddenly within the stratosphere; for winds under

[1] See Milham, *Meteorology*, 1914, pp. 15-16; Hann, *Lehrbuch*, 3d ed., 1914, p. 2; Young-*General Astronomy*, 4 Rev. ed., 1904, pp. 181-182; Stoney, *Transactions of the Royal Dublin Society*, 1892, 1897, and 1898, and *Astrophysical Journal*, 11, 36, 1900; *ibid.*, 11, 251, 1900; *ibid.*, 11, 325, 1900; *ibid.*, 12, 201, 1900.

[1] *C. R.*, 170, 604, 1920.

[2] J. V. Sandstrom has considered the same questions, and by a less direct analysis has been led to the same conclusions; see Ueber die Beziehung zwischen Temperatur und Luftbewegungen in der Atmsophare unter stationaren Verhaltnissen, Ofversigt af k. Vetenskaps Akkademien Forhandlinger, Stockholm, 1901; and Ueber die Temperaturwerteilung in den aller hochsten Luftschichten, Arkiv. for Math., Astr. och Fysik, Stockholm, 1907. On the physical causes of the occurrence and position of the tropopause, see W. J. Humphreys, Physics of the Air, and in another form in MONTHLY WEATHER REVIEW, 1919; 47, 162-163, and Science, 49, 156-163, 1919.

[1] Cf. a shorter abstract in the REVIEW, Jan. 1920, 48: 11.

10 m/s there seems to be little change, some of them even increasing slightly within the stratosphere (see fig. 1). As soon as the surface layers are left behind the wind direction becomes remarkably constant and remains nearly the same from 4 kilometers up to the highest point reached—no effect is seen in the direction on entering the stratosphere. The horizontal pressure and temperature gradients were computed from the winds on a few typical days, according to the procedure given in the *Computer's Handbook*. The resulting curves show that the horizontal pressure gradient remains nearly constant throughout the troposphere but suddenly begins to decrease with remarkable rapidity as soon as the tropopause is passed, and approaches zero at about 18 or 20 kilometers; however, even if the pressure gradient never increased above the value shown at the highest level for which results were available, the decrease in density would account for winds of considerable velocity. Within the troposphere the horizontal temperature gradient at right angles to the average direction of the wind increases gradually with height, the air being colder over the cyclone than over the anticyclone, but on entering the stratosphere a very sudden and large reversal takes place and the gradient changes to a value somewhat greater than that at the top of the troposphere, and in the reverse direction; after a kilometer or two this value decreases again and becomes very nearly zero at heights of 18 or 20 kilometers.—*E. W. W.*

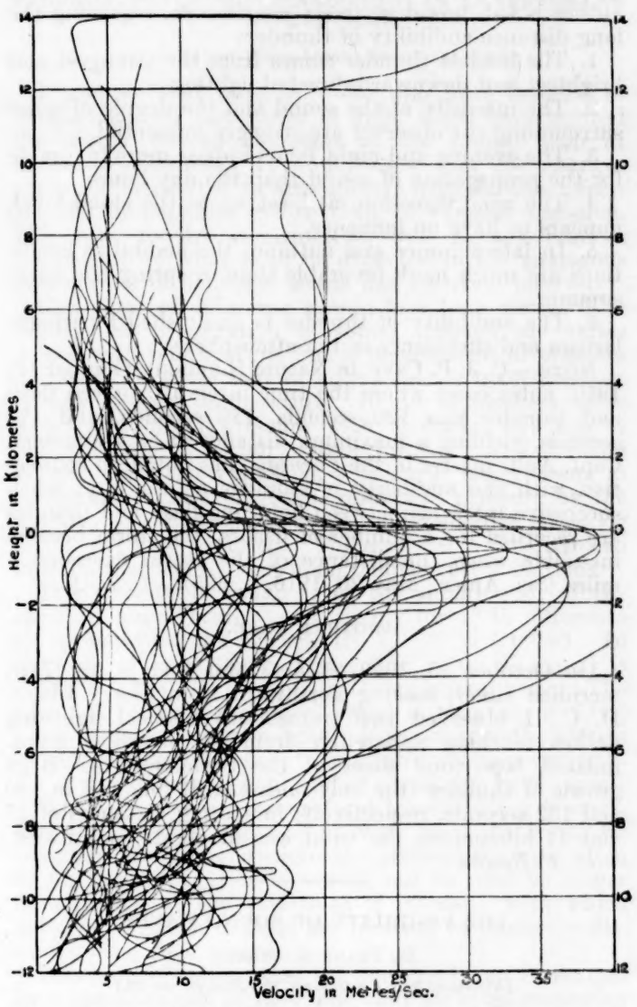

FIG. 1.—Variation of wind velocity with height. (Heights are taken relative to the base of the stratosphere as given by temperature records.)

ON AN APPARATUS FOR THE STUDY OF THE FORMATION AND PERSISTENCE OF FOG.

By A. TRILLAT and M. FOUASSIER.

[Abstracted from *Comptes Rendus, Paris Acad.*, Mar. 17, 1919, pp. 570-572.]

The condensation of water vapor in the air depends not only upon the quantity of vapor and the changes of temperature, but also upon whether the particles are solid, liquid, or ionized. These factors have been studied principally by Coulier, Mascart, Aitken, Wilson, and Langevin. The present studies were made during the war to devise, if possible, some apparatus which could be employed in forecasting the possibilities of fog. The work rested upon two premises: First, that the possibility of fog in air of given temperature, pressure, and humidity depends chiefly upon the more or less persistent presence of solid or liquid particles; and, second, the expansion necessary to provoke the appearance of fog is less when the number of active particles in the air is great.

The instrument as described in an abstract by R. Corless[1] is as follows: "The apparatus consists of a closed glass vessel of 10 liters capacity, provided with an exhausting pump and a mercury manometer; also with a device for noting when fog of a standard quality has been produced. The air to be tested having been introduced into the vessel, the pressure inside is reduced by means of the pump until the standard fog is produced. The reading of the manometer then gives a measure of the difficulty of production of fog."

The nuclei provided by smoke from the combustion of vegetable and animal products were found to be especially active.

Ammonium salts, magnesium chloride, and emanations of mineral acids possess to a great degree the property of condensing atmospheric moisture about them. On the other hand, the carbonates, silicates, and oxide of iron, which constitute a large proportion of atmospheric dust are less active and less persistent in forming fog. Microorganisms are also effective as nuclei. Some particles are soluble and some insoluble in water vapor, the first appearing to form the more persistent fogs. These experiments, it is pointed out, may explain the difference in the persistence of fogs between cities and open fields.—*C. L. M.*

"STORMS OF COLD" AND THEIR PATHS.

By A. BALDIT.

[Reprinted from Science Abstracts, Sec. A, Aug. 30, 1919, § 995.]

Thunderstorms are usually divided into two classes, (*a*) heat storms and (*b*) storms in depressions. The former are usually local in character, the latter accompany line-squalls, which are experienced in the southern sectors of depressions. The author describes a third type of thunderstorm, namely, "storm of cold," which occurs in a cold zone of air advancing from the north into a region where temperature is high, and upper winds are from the south. In these circumstances cumulo-nimbus clouds developing into thunderstorms are formed on the southern boundary of the cold wave and are carried northward by the upper south wind in a direction opposite to that of the north wind at the surface. Thus the storms travel backwards through the zone of cold air.—*R. C.*

[1] Science Abstracts, July, 1919, pp. 310-311.

A WIRELESS STORM DETECTOR FOR THE CENTRAL LIGHTING STATION.

By HERBERT T. WADE.

(Abstracted from *Scientific American Monthly*, January, 1920, vol. 1, pp. 18–21.)

At large power stations, such as that of the Waterside Station of the New York Edison Co., considerable difficulty in supplying sufficient current may arise with a sudden darkening of the sky at unusual times. This is often true of thunderstorms, when the sky will become dark almost without warning, and thousands of lights will be switched on all over the city almost instantly, increasing the load to such an extent that the power station, unless prepared for such an emergency, can not meet the demand. The substations merely start additional rotary converters, but the load falls back upon the central station.

To combat this the Waterside Station has had mounted on its roof for several years wireless antennæ so arranged that the electrical impulses from a very distant thunderstorm are caused to ring a bell in an office below. When the storm is 100 miles away, and there are no visible signs of its presence the bell will ring every few minutes, with increasing frequency as the storm approaches, until finally when the storm may still be an hour away, the bell will ring constantly. This gives a warning of several hours, which is quite sufficient to call into service boilers which have been banked. Hence, when the storm breaks and the city calls suddenly for light these reserve boilers will have steam ready to turn additional dynamos and supply the required current.—*C. L. M.*

THE AUDIBILITY OF THUNDER.

By C. VEENEMA.

(Abstracted from *Das Wetter*, June, 1917, pp. 127–130; Aug.–Sept., 1917, pp. 187–192; Dec., 1917, pp. 258–262; Mar.–Apr., 1918, 56–68.)

There are two methods of determining the distance of thunder sources—the first by measuring the actual distance and the second by determining the time interval between lightning and thunder. The first method requires at least two observers, or as many more as possible, who will report the time of first thunder, the time of nearest approach of the storm, and whether or not the storm passed directly over the observer. In this manner the path of the storm can be constructed very accurately, and the distance of the thunder determined for any time from a given station. This plan is not feasible for storms approaching from the sea or for those observed over the sea. There is also danger that the first thunder may be confused with other noises, or that the direction may be in error, but these difficulties are largely overcome with practice. The second method, that of determining distance by time interval between lightning and thunder, has advantages and disadvantages also. Only one observer is needed, and the results of his observation can be obtained at once. On the other hand, when there is continuous thunder and frequent lightning, especially at night, when other conditions for obtaining large values for thunder audibility are propitious, it is often difficult to associate a given peal of thunder with its proper flash of lightning. Moreover, the circumstances surrounding the observer must be favorable, or, as frequently happened to the author, the observation will be lost by the passing of a wagon, the roar of the wind, or the noise of the rain, after having counted seconds for a considerable period.

By almost continuous observation of thunderstorms from 1895 to 1916 the following distances occurred for a certain group of observations: On 9 occasions, between 30 and 40 kilometers; on 12 occasions, between 40 and 50 kilometers; on 2 occasions, between 50 and 60 kilometers; on 2, between 60 and 70 kilometers; on 2, between 70 and 80 kilometers; on 1, between 80 and 90 kilometers; and finally on 2 occasions over 100 kilometers. It is of interest to inquire what the maximum distance is, to which thunder could be heard under the most favorable conditions, but this question is dependent upon so many extraneous influences that it is difficult to answer. The author is led, however, to six conclusions, regarding the long distance audibility of thunder:

1. The loudest thunder comes from the strongest and brightest and downward-directed lighting.
2. The intensity of the sound and the degree of quiet surrounding the observer are strongly influential.
3. The evening and night hours appear more favorable for the propagation of sound than the day hours.
4. The wind direction, at least up to the cloud level, appears to have no influence.
5. In late summer and autumn, the audibility conditions are much more favorable than in spring and early summer.
6. The audibility of thunder is diminished by irregularities and turbulence in the atmosphere.

NOTE.—C. J. P. Cave, in Nature (London), October 16, 1919, notes cases where the time interval between flash and thunder was 120 seconds, 170 seconds, and 189 seconds, yielding a maximum distance of 63 kilometers. Capt. Ault, master of the *Carnegie*, has noted, in connection with the audibility of thunder at sea, that when successive intervals between lightning flash and thunder are recorded for a number of flashes, the storm became inaudible when the distance of the storm exceeded 5 miles (Sci. Amer., May 20, 1916, p. 525).—*C. L. M.*

ANOTHER CASE.

On October 16, 1919, at 5:43 and 5:44 p. m. (75th meridian time), looking northward from Chevy Chase, D. C., I observed two tremendous vertical lightning flashes reaching apparently from the overflow mammilated top cloud sheet of the thunderstorm. Brief growls of thunder (the only ones heard) followed in 140 and 132 seconds, respectively, indicating distances of 47 and 44 kilometers; the wind was moderate, southwest. —*C. F. Brooks.*

THE VISIBILITY OF SOUND WAVES.

By FRANK A. PERRET.

[Abstracted from *L'Astronomie*, May, 1919, pp. 193–196.]

Several instances are described in which the sound waves emanating from terrific explosions in volcanoes have actually been made visible by variations in the refraction of light through them. The following explanation is given: "* * * The sound is propagated in the air by means of compression and rarefaction waves, projected radially. The conditions for the production of these arcs are sudden explosions of great magnitude. If they are sufficiently violent, one can imagine that the waves of rarefaction and condensation would change the indices of refraction and reflection, and these zones would be visible by contrast. The visibility by contrast of zones of cold and warm air is well known, and we can easily conceive of an analogous

effect. It is a question of the *degree* of condensation and rarefaction. In short, an explosion produces in the air waves of compression and rarefraction which are perceived by the ear as sound, and also can be seen by unequal refraction, if they are sufficiently strong." These phenomena are seen as concentric circles about the point where the explosion occurs; generally, the top of a volcano.—*C. L. M.*

PROPAGATION OF SOUND AND LIGHT IN AN IRREGULAR ATMOSPHERE.

[Reprinted from *Nature*, London, June 13, 1918, p. 284.]

I suppose that most of those who have listened to (single-engined) aeroplanes in flight must have noticed the highly uneven character of the sound, even at moderate distances. It would seem that the changes are to be attributed to atmospheric irregularities affecting the propagation rather than to variable emission. This may require confirmation; but, in any case, a comparison of what is to be expected in the analogous propagation of light and sound has a certain interest.

One point of difference should first be noticed. The velocity of propagation of sound through air varies indeed with temperature, but is independent of pressure (or density), while that of light depends upon pressure as well as upon temperature. In the atmosphere there is a variation of pressure with elevation, but this is scarcely material for our present purpose. And the kind of irregular local variations which can easily occur in temperature are excluded in respect of pressure by the mechanical conditions, at least in the absence of strong winds, not here regarded. The question is thus reduced to refractions consequent upon temperature variations.

The velocity of sound is as the square root of the absolute temperature. Accordingly for 1° C. difference of temperature the refractivity $(\mu-1)$ is 0.00183. In the case of light the corresponding value of $(\mu-1)$ is 0.000294×0.00366, the pressure being atmospheric. The effect of temperature upon sound is thus about 2,000 times greater than upon light. If we suppose the system of temperature differences to be altered in this proportion, the course of rays of light and of sound will be the same.

When we consider mirage, and the twinkling of stars, and of terrestrial lights at no very great distances, we recognize how heterogeneous the atmosphere must often be for the propagation of sound, and we need no longer be surprised at the variations of intensity with which uniformly emitted sounds are received at moderate distances from their source.

It is true, of course, that the question is not exhausted by a consideration of rays, and that we must remember the immense disproportion of wave lengths, greatly affecting all phenomena of diffraction. A twinkling star, as seen with the naked eye, may disappear momentarily, which means that then little or no light from it falls upon the eye. When a telescope is employed the twinkling is very much reduced, showing that the effects are entirely different at points so near together as the parts of an object glass. In the case of sound, such sensitiveness to position is not to be expected, and the reproduction of similar phenomena would require the linear scale of the atmospheric irregularities to be very much enlarged.—*Lord Rayleigh.*

PROPAGATION OF SOUND IN AN IRREGULAR ATMOSPHERE.

By G. W. STEWART.

[Paragraph and synopsis reprinted from *The Physical Review*, vol. 14, No. 4, pp. 376-378. Article is reprinted in *Aeronautics*, Nov. 20, 1919, p. 467.]

Lord Rayleigh's recent reference [1] to and explanation of the "highly uneven character of the sound" from aeroplanes leads the writer to make a record of three additional facts.

Under poor atmospheric conditions, lower frequencies in aeroplane engine sounds become relatively enhanced; under good conditions frequencies of order of 1,000 d. v. are heard at greatest distances. The former is explained by irregularities in the atmosphere and the latter by characteristics of audition.

Intensity of the sound varies much more rapidly than as the inverse square, crude observations giving much more nearly inverse sixth and fourth powers for maximum ranges under fair and good listening conditions, respectively.

SOME UNSOLVED PROBLEMS IN CANADIAN WEATHER.

[Reprinted from Meteorol. Off. Circular, Nov. 1, 1919, pp. 4-5.]

Previous to the meteorological luncheon at the Bournemouth meeting of the British Association for the Advancement of Science, Sir Frederick Stupart read a paper before Section A, on "Some unsolved problems in Canadian weather," making special reference to the climatic peculiarities of the Province of Alberta. He referred to the pressure and temperature conditions of two recent consecutive Januaries in which the mean temperatures at Calgary were 16° F. and 47° F., respectively. During the cold January the mean pressure of the month in the northwest of Canada was as high as 30.75 inches, but in the mild January only 29.97 inches. In the cold January there was intense terrestrial radiation and light northerly winds prevailed, but in the mild January with the low pressure, föhn (chinook) winds persisted, and the temperatuer in Alberta was high continuously. The föhn effect was due to the winds from the Pacific having to traverse four mountain chains so that they were dynamically warmed winds. In the discussion that followed Sir Napier Shaw pointed out certain objections that applied to the conventional explanation of föhn effects.

CLIMATE OF THE BELCHER ISLANDS OF HUDSON BAY.

By ROBERT J. FLAHERTY.

[Excerpt from article on "The Belcher Islands of Hudson Bay" in *Geog. Rev.*, June, 1918, vol. 5, pp. 433-458 (pp. 453-454).]

The climate of the islands differs widely from that of the opposite mainland. Compared with weather reports from Great Whale River for the same period, our observations gave a far greater proportion of overcast skies and fogs, stronger and more constant winds, but higher and more equable temperatures. From October [1915] till early December winds of a velocity up to 50 miles were almost constant, and the sky was continuously overcast.

[1] See this REVIEW, p. 163.

No snow covered the ground permanently until November 15, and no ice was formed in the small lakes near the wintering base until December 4, when the long periods of winds ceased and a fortnight of calm, clear weather set in. The mercury did not fall below zero until January 2—a weather condition without precedent in my experience of the North. Great Whale River early in December had a minimum temperature of −30° and recorded a constant average for the period well below zero [F].

On January 2 [1916] winter commenced in earnest. The month was characterized by constant drifting winds of a maximum force of 70 miles; calm days were unknown; and the average temperature was −16°. In February the winds abated; there were many days of sunshine, a few of them almost calm. The average temperature for the month was −19° [F]. Throughout March strong winds again prevailed; by the end of the month the snowfall for the winter had reached its maximum, 4 feet; the average temperature for the month rose to −9°. In April and May there was the usual prevalence of wind, and several blizzards occurred, each covering a period of from one to two days. In the latter part of May the weather broke and became warm and summery; in fact, there were heavy thunderstorms at this time. On May 28 sledging over the ice fields was at an end, and by June 10 the field ice surrounding the islands had blown off to southward. Then commenced the most trying time of the year; for hardly two days together did fair weather obtain. From mid-June onward to the time of our departure on September 13 exceedingly heavy gales of wind of from one to three days' duration occurred in every week. The prevailing direction of the winds was south-southwest for not only that period but for the entire year. Days of sunshine were rare; the sky was generally overcast; and rains, accompanied usually by heavy southeast winds, were frequent. According to the natives the weather we experienced during that year was not at all typical; usually, they said, the winds were fewer and less violent, and the temperature during the winter was lower. The remarkable lateness of the freeze-up (December 23) was, they said, without precedent. The minimum temperature for the winter was −48° as compared with the lowest mean reported temperature on the mainland of −55°. The maximum thickness of fresh-water ice was 5½ feet, and of sea ice, 5 feet. The maximum temperature for the summer, occurring on July 25 at noon, was 70°.

CLIMATE OF THE GALAPAGOS ISLANDS.

By G. M. McBRIDE.

[Excerpts from article on "The Galapagos Islands" in *Geogr. Rev.*, September, 1918, vol. 6, pp. 229-239 (pp. 236, 237, 239).]

The Galapagos Islands lie at the meeting place of two ocean currents. * * * The Humboldt Current, during nine months of the year when the trades are blowing constantly, divides into two branches off the coast of Ecuador, and larger one veering westward toward the Galapagos. Its velocity is very great, sometimes as much as 75 miles a day. * * * From the northeast a warm current that has come down along the coast of Central America enters this same region. The meeting of the different streams produces what has been called "current doldrums," the current turning east or west, north or south, according to the direction of the wind. The fact that the current from the southeast is cold and that it flows along a desert coast where few streams enter the sea, while the northern current has a higher temperature and bathes a shore whose numerous torrents in the rainy season come laden with sediment, probably accounts for the greater resemblance of fauna and flora to those of Central America.

The climate of the Galapagos is far from equatorial. The presence of cold water from the Humboldt Current reduces still farther the mild temperature to be expected in an oceanic climate. Darwin reported a temperature of 60° F. 1 foot below the surface on the southeast side of Albermarle, and Wolf records surface temperatures of 70° F. and 73° F. at several points between the islands. So marked is the effect of the cold current that, while the geographical equator passes directly through the group of islands the thermal equator lies some distance north, throughout many months departing over 20° of latitude from the geographical line.

This favors the development of strong southeast trades at the islands during most of the year. A further contributing influence to the cool temperature of the ocean in this region is probably found in the upwelling of cold water from the ocean depths.[1] These factors combine to make the Galapagos cooler than any other equatorial land at so near sea level. Even on the lowlands the heat is modified, but the effect of air currents from off a cool water surface is most striking as one ascends the slopes toward the interior.

The zones of vegetation find their explanation in the varying meteorological conditions that exist at different levels. Both in temperature and moisture is this difference notable. Though continuous records are lacking, the observations made by scientists at different seasons of the year give a fairly accurate idea of the climate. While near sea level the temperature often rises to 90° F. (even higher in places sheltered from the wind), Wolf found a fall of one or two degrees for every hundred meters of ascent. Upon the middle slopes some 400 to 600 feet above the sea the average temperature was less than 70° F. On the summit of the hill of San Joaquin in Chatham Island at an elevation given as 2,330 feet, he recorded a mid-day temperature of 57.2° F. during heavy mist and a strong southeast wind. There is little variation from day to day and no marked seasonal difference A passing cloud, or the presence of a fog, produces greater change of temperature than do the seasons, while the greatest range occurs from day to night. After sundown it becomes actually cold on the higher hills, and travelers who pass the nights there in the open air huddle about their camp fires even during the milder months of the year.

The northern islands lie more within the influence of the warmer ocean waters from the Gulf of Panama, those toward the south receiving the full effect of the cold Humboldt Current. The low temperature of the ocean waters had made possible the occurrence of some forms of life rarely found outside the higher latitudes. Several kinds of seals are common, among them *Otaria australis*, found also on the coast of Peru and Chile and about the islands of Tierra del Fuego. Penguins, whose range is generally restricted to the coast of subpolar regions, are here found directly upon the equator; and the great albatross so common about Cape Horn has followed the cold current toward the north, nesting by hundreds upon the island of Hood.

[1] Cf. R. E. Coker: Ocean Temperature off the coast of Peru, *Geogr. Review*, vol. 5, 1918, pp. 127-135.

RAINFALL AND MOISTURE.

In amount of moisture the zones of elevation are still more marked. The lower levels are almost rainless. During the first four months of the year some showers may fall, but completely rainless years are not unknown. The nature of the soil is such that any water which may fall immediately disappears beneath the rock-strewn surface. Some who have visited the islands in unusual seasons have been surprised to find the lower lands green with vegetation; but in normal years there is a very serious lack of moisture.

In contrast with the desert conditions characteristic of the slopes near the sea, the uplands are bountifully supplied with moisture. Besides a well-marked period of frequent convectional showers extending from February to May when the southeast trades are interrupted and equatorial calms prevail, there is a so-called summer, approximately from June to January, when, though the tropical downpours have ceased, the hills are drenched in dense mists (*garúas*) sufficient to keep the roads filled with mud, make books and papers mold in a short time, and quickly rust unpainted iron. Light rains may fall here at any season. On the southeast side of the islands, as on corresponding slopes of the hills, the moist zone extends several hundred feet lower, while the northern exposures, sheltered from the rain-bearing winds, present a striking contrast in their relatively arid character. The effect of abundant moisture on the uplands is evident not only in the ranker growth of vegetation but even upon the lava flows that stretch from near the summits to the sea. The upper sections of these flows are often badly weathered and covered with plants that have found lodgment upon their surfaces, while the lower reaches, that cross the arid zone beneath, show little effect of atmospheric action but lie in solid blocks of black obsidian. But for the constant humidity on the highlands the soil itself would still resemble that of the desert lower grounds.

* * * No storms visit the group during any period of the year.

THE CLIMATE OF SÃO PAULO AND CEARA, BRAZIL.

[Reprinted from Geographical Review, New York, December, 1919, vol.-8, pp. 356-357.]

Mr. R. C. Mossman, who was for some years connected with the Argentine Meteorological Service, is at present devoting attention to the climatology of various portions of South America. Hitherto by far the greater part of all available published data for South America have covered varying periods of time and have not been reduced to a homogeneous system. Hence, these observations have not been directly comparable and have lacked the accuracy which is an absolute essential in all good climatological work. In two recent communications (Quart. Journ. Royal Meteorol. Soc., January, 1919), Mr. Mossman gives the results of compilations which he has completed for the State of São Paulo and for the city of Fortaleza, in the State of Ceara, Brazil. The chief interest of São Paulo centers in its coffee industry, but the region is also becoming more and more a cattle country. Mr. Mossman has now reduced the temperatures and rainfalls of São Paulo, as published, to a homogeneous system. The data were extracted from the Dados Climatologicos of the Servico Meteorologico de São Paulo, issued since 1887, the last volume published dealing with the year ending November, 1912. These bulletins give an abundance of climatic information with a detail "such as is available for no other portion of South America." Mr. Mossman's summary includes all the essential facts:

The special interest of the State of Ceara lies in the fact that this region is periodically visited by severe droughts, and the object of the present study is to summarize the results regarding rainfall obtained from 1849 to 1915, the ultimate end in view being an investigation which it is hoped may lead to a clew concerning the "precise mechanism associated with these droughts." The rainfall data are given in great detail, in convenient and easily accessible form, and will prove of distinct value to all those who are interested in the economic climatology of Brazil.—*R. DeC. Ward.*

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RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

C. FITZHUGH TALMAN, Professor in Charge of Library.

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Alfalfa seed growing and the weather, with particular reference to conditions in Utah. (Utah agricultural college experiment station. Bull. No. 171.) Logan, Utah. 1920. 31p. 23 cm. [See MONTHLY WEATHER REVIEW, May, 1919, **47**: 330-332.]

Bjerknes, J.

On the structure of moving cyclones. Kristiania. 1919. 8 p. 30 cm. [See MONTHLY WEATHER REVIEW, Feb., 1919, **47**: 95-99.]

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C. F. TALMAN, Professor in Charge of Library.

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SPECIAL OBSERVATIONS.

SOLAR AND SKY RADIATION MEASUREMENTS DURING MARCH, 1920.

By H. H. KIMBALL.

(These data for January to April, 1920, inclusive, will be published in the April REVIEW.)

MEASUREMENTS OF THE SOLAR CONSTANT OF RADIATION AT CALAMA, CHILE.

By C. G. ABBOT, Director.

[Astrophysical Observatory, Smithsonian Institution, Washington, Apr. 30, 1920.]

In continuation of preceding publications, I give in the following table the results obtained at Calama, Chile, in February, 1920, for the solar constant of radiation. The reader is referred to this REVIEW for February, August, and September, 1919, for statements of the arrangement and meaning of the table.

The results for February, like those of January and the latter part of December, run extremely high. Owing to unusual cloudiness, which at times even went so far as to produce rain, a most unusual circumstance at Calama, there were very few days on which it was possible to determine the solar constant of radiation by the older and fundamental method. Attention is called, however, to the determinations of February 10 and February 25 to show that the old method and the new are still in close agreement.

Date.	Solar constant.	Method.	Grade.	Transmission coefficient at 0.5 micron.	Humidity.			Remarks.
					ρ/ρ SC.	V. P.	Rel. hum.	
1920. P. M.	*Cal.*					*Cm.*	*Per cent.*	
Feb. 6	1.978	$M_{1.01}$	U+	0.826	0.385	0.95	48	Cumuli scattered about sky.
	1.965	$M_{1.01}$						
	1.974	W. M.						
A. M. 7	1.942	$M_{1.72}$	U+	.813	.290	.84	64	Cirro-cumuli over most of sky.
	1.954	$M_{1.02}$						
	1.946	W. M.						
8	1.954	$M_{1.11}$	S—	.823	.409	.92	56	Cumuli scattered over east, north, and south.
	1.952	$M_{1.02}$						
	1.953	W. M.						
9	1.984	M_2	S	.823	.321	.77	67	Cumuli around horizon in east, north, and south.
	1.977	$M_{1.5}$						
	1.982	W. M.						
10	2.009	E_0	VG+	.821	.276	.71	64	Cirri low in east. Cumuli forming around horizon in east.
	2.012	M_3						
	1.985	M_2						
	1.978	$M_{1.5}$						
	1.994	W. M.						
11	1.949	M_2	S—	.841	.428	.65	48	Cirro-cumuli scattered about east.
	1.975	$M_{1.28}$						
	1.958	W. M.						
P. M. 12	1.977	$M_{1.02}$	U+	.842	.572	.79	39	Thin cirri spread over much of sky, especially in east.
13	1.975	$M_{1.03}$	U+	.825	.504	.77	37	Thin cirri scattered about sky.
	1.950	$M_{1.02}$						
	1.962	W. M.						
14	1.946	M_2	S	.822	.340	.60	38	Few streaks of thin cirri in east and west. Cumuli forming in distant east.
	1.958	$M_{1.5}$						
	1.951	W. M.						
P. M. 15	1.951	$M_{1.02}$	S—	.827	.486	.75	39	Very thin cirri spread over much of sky. Some cumuli in east.
A. M. 16	1.976	M_2	S	.830	.363	.58	40	Thin ciri scattered about sky, especially in west.
	1.968	$M_{1.5}$						
	1.973	W. M.						
18	1.971	$M_{1.23}$	S—	.829	.456	.66	36	Cirri scattered about sky.
19	1.996	M_3	S—	.830	.284	.57	49	Cirri low in east, west, and north.
	1.976	M_2						
	1.983	W. M.						
P. M. 20	1.982	M_2	S—	.838	.438	.53	26	Cirri in north and east. Cumuli in north and west.
24	1.973	$M_{1.05}$	S—	.835	.481	.84	38	Scattered cirri.
	1.961	$M_{1.03}$						
	1.967	W. M.						
A. M. 25	1.973	E_0	E—	.825	.265	.65	55	Some cirri around horizon in east, north, and west. Patch of cirro-cumuli in west.
	1.993	M_3						
	1.994	M_2						
	1.983	$M_{1.5}$						
	1.987	W. M.						
26	2.006	M_3	U+	.826	.261	.64	48	Cirri scattered about sky, especially in west, but disappearing gradually.
	1.972	M_2						
	1.983	W. M.						
27	1.963	$M_{1.5}$	S—	.836	.439	.76	43	Cirri scattered about whole sky.
	1.974	$M_{1.37}$						
	1.967	W. M.						
P. M. 28	1.953	$M_{1.09}$	S—	.839	.504	.90	43	Thin cirri scattered about sky.

WEATHER OF THE MONTH.

WEATHER OF NORTH AMERICA AND ADJACENT OCEANS.

GENERAL PRESSURE CONDITIONS.

By H. C. FRANKENFIELD, Supervising Forecaster.

North Pacific Ocean.—At Midway Island pressure was well above the normal during the first two weeks of the month, and moderately high, as a rule, during the third week, while thereafter it averaged somewhat low. At Honolulu pressure was high during the first decade of the month, and generally below normal thereafter.

Alaska.—High pressure prevailed during the first five days of the month, and general low pressure thereafter, although during the last few days of the month pressure near the coast was substantially above the normal. Over the Aleutian Islands, however, a decade of quite low pressure was followed by a more marked opposite condition during the remainder of the month. Temperatures were variable within moderate limits during the first half of the month, but much below normal during the second half.

United States.—The month was characterized by a remarkable series of great disturbances that moved across the country. There were six of these in all, and a seventh was in progress at the close of the month. Abnormally low pressures prevailed in every instance, 28.56 inches in one, and all, except one, were attended by severe gales and rains. Destructive tornadoes also occurred during the eastward movement of the storm of March 26–30, and an extensive and marked high-pressure wave with low temperatures followed the storm of March 1–7, but there were no other HIGH of consequence. The temperature average was high except during the first few days of the month.

North Atlantic Ocean.—Stations of observation at Bermuda and Horta. Except on a few days, pressure was above normal, decidely so from about March 5 to 15, inclusive.

NORTH PACIFIC OCEAN.

By F. G. TINGLEY.

The principal disturbance of the month on the North Pacific Ocean was that which prevailed at the end of the first and the beginning of the second decade over the western part of the ocean, affecting shipping on the northern steamer route between the 140th and 170th meridians, east longitude. Several vessels which were in the field of this depression reported barometric readings of 29 inches, or below. Fresh to strong gales were general over an extensive area and at intervals the wind reached the force of a whole gale. The highest winds were from the western quadrants.

East of the 170th meridian, east longitude, the weather was relatively quiet throughout the month except from about the 16th to the 24th when fresh to strong gales were encountered by a few ships in waters to the southward of the Alaskan Peninsula.

NORTH AMERICA.

By H. C. FRANKENFIELD, Supervising Forecaster.

The month of March, 1920, was indeed a remarkable one from a meteorological viewpoint. No less than seven disturbances of an abnormal character moved across the country, the dates of appearance and disappearance being as follows:

No. 1. March 1–7, inclusive.
No. 2. March 9–15, inclusive.
No. 3. March 13–17, inclusive.
No. 4. March 15–21, inclusive.
No. 5. March 24–27, inclusive.
No. 6. March 26–30, inclusive.
No. 7. March 29–April 3, inclusive.

There was much similarity in the development, movement and attendant phenomena of these storms, and the interval between them was so short that, with the exception of the first one, there was no succeeding HIGH of any considerable magnitude, and no unusually low temperatures. As a matter of fact, temperatures were above normal after the passage of the HIGH that succeeded the storm of March 1–7, but this early cold extended throughout the entire South, and on the morning of March 7 heavy frost occurred down to the southern limits of the mainland of Florida.

The storm of March 26–30 was attended by severe local storms and tornadoes on March 28, and these will be discussed in the April REVIEW.

NORTH ATLANTIC OCEAN.

By F. A. YOUNG.

The average pressure for the month was nearly normal at land stations on the coasts of Newfoundland, Canada, and the greater part of the United States, while it was slightly higher than usual at Key West and Bermuda. In the Azores the pressure was considerably above the normal and slightly below in northern European waters, causing a somewhat steeper gradient than usual between the two regions.

The number of days on which gales were observed was apparently not far from the normal over the greater part of the ocean, although in the 5-degree square immediately north of Bermuda they were recorded on 9 days, which is considerably more than usual.

According to reports received there was very little fog during the month, as it was not recorded on more than one day in any 5-degree square.

On March 1 there was a well-developed LOW central near the intersection of the 40th parallel and 65th meridian, while moderate to strong gales prevailed over a limited area west of the 60th meridian. This disturbance moved eastward with moderate speed, and on the 2d the center was near latitude 43°, longitude 55°, and southerly winds of gale force were still encountered in the easterly quadrants. During the next 24 hours the LOW moved but little, decreasing in intensity, although on the 3d a few reports were received denoting moderate northerly gales between the 50th and 60th meridians. The storm log from the French S. S. *Canada* is as follows:

Gale began on the 1st at 7:30 a. m. Lowest barometer reading 29.58 inches at 8 p. m. on the 2d; position 38° 45′ N., 58° 35′ W. End of gale on the 3d; highest force of wind, 11; shifts of wind near time of lowest barometer reading SE.–S.–SW.–WSW.–SSE.–WSW.–NNW.–N.

On the 5th Hatteras was near the center of a LOW, the barometer at that station reading 29.50 inches; only

moderate winds were recorded by vessels in the immediate vicinity, while moderate to strong gales prevailed over a portion of the steamer lanes, accompanied by comparatively high pressure. During the next 24 hours this disturbance moved northeastward along the coast, as on the 6th the center was near Nantucket, the weather conditions having changed but little. The disturbance continued its northeasterly drift and on the 7th was off the west coast of Newfoundland. At the same time there was a second LOW over the North Sea, and heavy weather was experienced over the greater part of the ocean north of the 40th parallel. The storm log from the British S. S. *Stanmore* is as follows:

Gale began on the 6th; position 42° 24′ N., 67° 52′ W. End of gale on the 7th. Highest force of wind, 10; shifts of wind, S.-W.

From the 8th to the 12th moderate weather with high pressure was the rule over the greater part of the ocean, although on the 11th and 12th moderate gales were reported over a limited area between the 20th parallel and the European coast.

By the 13th the storm area had extended to a considerable extent, reaching as far west as the 35th meridian, and there was a second disturbance central near the Virginia Capes, with southerly gales along the American coast between Nantucket and Charleston.

On March 14, as shown on Chart IX, this disturbance had increased considerably in intensity. Ireland was also surrounded by a well-developed LOW, and strong westerly gales covered the eastern and western sections of the steamer lanes.

Chart X for March 15, shows that both of these disturbances had decreased in intensity during the next 24 hours, as by the 15th the storm area had contracted in area, and comparatively few reports of gales were received. The storm log from the American S. S. *American Star* is as follows:

Gale began on the 12th. Lowest barometer 29.24 inches at 6 p. m. on the 13th; position 38° 20′ N., 71° 17′ W. End of gale on the 15th. Highest force of wind, 10; shifts of wind, SW.-W.

From the 16th to the 23d conditions over the ocean were comparatively featureless, although on the 21st a few reports were received denoting moderate gales between the 40th and 45th parallels and 55th and 63d meridians.

Charts XI to XIV show the wind and weather conditions during the period from the 24th to the 27th, both inclusive, with the nearly stationary storm area over the mid and eastern sections of the steamer lanes. The observer on the Belgian S. S. *Egalntier* states in the storm log:

Gale began on the 23d. Lowest barometer 29.80 inches at 9:30 a. m. on the 24th; position 45° 02′ N., 35° 19′ W. End of gale on the 28th. Highest force, 12; shifts of wind, N.-W.-NW.

On the 25th a few vessels between the 48th and 53d parallels and the 20th and 25th meridians encountered severe northerly gales, while light to moderate winds prevailed over the remainder of the ocean, except that one vessel about 200 miles north of Bermuda reported a westerly wind of about 50 miles an hour. This disturbance must have been very local in its character, as all other vessels in that vicinity encountered moderate winds.

The observer on the British S. S. *Pannonia* reports as follows:

On March 31, at 2 a. m. (G. M. T.), in latitude 37° 20′ N., longitude 65° 30′ W., we encountered a cyclonic squall. The water was boiling and whirling in several places, the highest spiral being about 40 feet above the water. A strong westerly wind, force 9, was blowing at the time, with a rough sea and steady barometer of 29.94 inches. Cumulus and cirro-cumulus clouds.

NOTES ON WEATHER IN OTHER PARTS OF THE WORLD.

Nova Scotia.—Halifax, March 2.—Arctic ice packs, literally black with walrus, seals and other polar creatures, are the largest within memory, according to reports * * * [of] sailors and overland travelers.

The solid ice extends farther south than at any time within years, with the bays and inlets fringing the Newfoundland coast locked tightly.

Newfoundland is ice bound and railroads are completely tied up. Inhabitants in the interior are suffering intensely.—*Chicago Evening Journal, March 2, 1920.*

Cuba.—Habana, March 21.—A heavy downpour of rain accompanied by a hailstorm of unprecendented violence swept over the city this afternoon, flooding houses in the lower sections of the city, paralyzing street car traffic for nearly two hours and causing numerous minor accidents and loss of small craft in the harbor. * * * The hailstorm, the first in sixteen years, is said to have been the heaviest and the hailstones the largest ever seen here.—*Washington (D. C.) Evening Star.*

British Isles.—Like the three months which preceded it, March was notable for its unusual mildness. * * * During the greater part of the month there was a preponderance of winds from westerly or southwesterly quarters, winds which were, moreover, frequently accompanied by copious precipitation in the form of snow, sleet, hail and rain. * * * A striking feature of the month was the frequency of warm days; at Kew Observatory, for instance, the maximum temperature was between 55° F. and 66° F. on 16 occasions, and fell below the normal on only five days. * * * The general rainfall expressed as a percentage of the average was: England and Wales, 150; Scotland, 137; Ireland, 129. In London (Camden Square) there was frequent but light rain. The mean temperature was 46.7° F., or 4.6° above the average, being the highest value recorded for March during the 63 years' record.—*The Meteorological Magazine, April, 1920, p. 51.*

Baltic region.—In western Europe March was not so disturbed as February, but in the British Isles and eastward into the Baltic the weather continued unusually warm, and at Helsingfors and Reval the sea was unusually free from ice. Early in the month a gale in the Baltic caused loss of life.—*The Meteorological Magazine, April, 1920, p. 56.*

Mediterranean.—Paris, March 27.—Two French steamers * * * have been missing since the recent hurricane over the Mediterranean, and it is believed they were lost with all hands [42] * * *.—*New York Evening Post, March 27, 1920.*

Near East.—The cold and stormy conditions of February in the Near East continued into March, with an intensity unequaled for many years, culminating about the 9th in a hurricane in the Black Sea, which destroyed an American Red Cross steamer, with the loss of 500 invalided soldiers.—*The Meteorological Magazine, April, 1920, p. 56.*

DETAILS OF THE WEATHER OF THE MONTH IN THE UNITED STATES.

CYCLONES AND ANTICYCLONES.

By R. HANSON WEIGHTMAN, Meteorologist.

Cyclones.—The month was unusual on account of the number of secondary developments, of which there were 10 within the confines of the United States and of these 5 first appeared over the Rocky Mountain and Plateau Regions. The table which follows gives the number of LOWS by types.

Lows.

	Alberta.	North Pacific.	South Pacific.	Northern Rocky Mountain.	Colorado.	Texas.	East Gulf.	South Atlantic.	Central.	Total.
March, 1920.....	4.0	3.0	1.0	2.0	3.0	1.0	1.0	1.0	2.0	18.0
Average number, 1892–1912.....	3.6	2.1	1.1	0.3	1.9	1.3	0.4	0.3	0.7	11.8

Anticyclones.—The number of HIGHS was slightly above the average and anticyclones were fairly well distributed with regard to type as indicated in the table below.

Highs.

	North Pacific.	South Pacific.	Alberta.	Plateau and Rocky Mountain region.	Hudson Bay.	Total.
March, 1920.....	1.0	1.0	7.0	1.0	0.0	10.0
Average number, 1892–1912.....	0.9	0.7	5.6	0.9	0.5	8.5

THE WEATHER ELEMENTS.

By P. C. DAY, Climatologist and Chief of Division.

[Weather Bureau, Washington, May 1, 1920.]

GENERAL SUMMARY.

March, 1920, fully maintained its reputation as a stormy month over many portions of the country, the pressure, temperature, wind, rain, and other phenomena contributing at some time in making the month as a whole one of marked extremes.

Chief among the notable weather events of the month may be mentioned the following:

Severe cold over the southeastern States at the beginning of the month, when freezing temperatures extended into the central portions of the Florida Peninsula, and killing frosts, locally, to near the southern extremity. The temperatures over the extreme southern portions of the State were as low as, or lower than ever before recorded in March, and much damage was sustained by the early spring trucking interests.

The severe wind and snow storms of the 5th and 6th over the northeastern States, particularly in New England, where the snowfall was in many cases the heaviest ever recorded in March. The storm was comparable with the great "blizzard" [1] of March, 1888, and in some sections it is reported as being even more severe than that. High winds drifted the snow to such an extent as to blockade traffic completely, which in places was not resumed for a week or more.

[1] See note on the term "blizzard," MONTHLY WEATHER REVIEW, February, 1920, 48: 82.

The severe cold that overspread the Rocky Mountains and thence eastward and southeastward to the Atlantic and Gulf States from the 6th to 8th brought the lowest temperatures of the month over those regions, and in numerous instances the lowest temperatures ever reported in March. During this period temperatures fell to 40°, or more, below zero in many northern districts, and below-zero temperatures were reported at exposed points as far south as Oklahoma, Tennessee, and western North Carolina. Over the Florida Peninsula, however, the temperatures were not as low as those reported at the beginning of the month.

On the 15th and 16th one of the severest storms ever experienced developed over the upper Missouri Valley and moved to the northward of Lake Superior. The barometric pressure over a large area, including the Dakotas and portions of adjoining States reached lower points than ever before known in that region. Snow fell continuously in portions of the storm area for nearly two days, and high northwest winds drifted it to such an extent as to interfere greatly with traffic. In portions of North Dakota it is described as one of the worst blizzards of record. Five lives were lost due to freezing, and stock, unprotected and already weak from the long cold winter and the frequent lack of food, suffered severely, and much loss was sustained.

On the night of the 22d one of the most brilliant and extensive auroras ever witnessed was observed from all States, particularly in the central and eastern districts, where the absence of clouds permitted unusual opportunity for its wide display. Cloudy weather prevented its general observance in many districts west of the Mississippi River. (A detailed account of this aurora will be published in an early issue of this REVIEW.)

On the afternoon of the 28th, in the southeast quadrant of an area of low pressure moving from the middle Plains region toward the Great Lakes, a series of 9 tornadoes developed in the vicinity of the southern end of Lake Michigan, particularly near Chicago, where 45 lives were lost and several million dollars worth of property was destroyed. Another series of severe storms, some with tornadic characteristics, occurred about the same time in portions of Georgia and surrounding States, where 43 lives were lost and considerable property was destroyed. Full reports of these storms will be found in the April issue of this REVIEW.

PRESSURE AND WINDS.

The pressure was frequently low over the western and northern districts, and it remained high for considerable periods in the Southeastern States. As a result, the averages for the month were below normal over practically all portions of the United States west of the Mississippi and north of the Ohio, and over Canada as well, as far as disclosed by observations. The negative departures were unusually large over the middle Mississippi Valley and central Plains regions and thence northward into Canada.

The pressure distribution favored frequent high winds in many parts of the country, and over portions of the Plains region and Mississippi Valley the month as a whole had the greatest wind movement ever recorded. The winds were particularly high over northeastern districts on the 5th and 6th, and over the northern Plains region and upper Mississippi Valley on the 15th and 16th. On the 28th high winds prevailed locally from the middle Mississippi Valley to the Great Lakes and in portions of

the East Gulf States, a number of localities reporting severe tornadoes, which are referred to elsewhere.

The low pressure in northern districts favored southerly winds between Texas and the Great Lakes and over much of the country to the eastward. From the upper Lakes west to the Rocky Mountains the winds were mostly from the NW. (See Chart VII.)

TEMPERATURE.

The warmest periods of the month were mostly during the last decade, principally from the 27th to the 31st, over the districts east of the Rocky Mountains, but in the Plateau and Pacific Coast States the warmest periods were about the 13th and 14th, and again on the 20th and 21st.

In the cold period of the 1st and 2d minimum temperatures were from 25° to 35° below zero F. at some exposed places in northern New York and the interior of New England, and freezes and killing frosts on the Gulf coast and Florida peninsula did much damage to vegetation. Killing frosts also occurred over portions of the Pacific States at this time. The most extensive cold area of the month, embracing practically all portions of the country save the extreme south and west, occurred from the 6th to the 8th. Over many northern districts the minimum temperatures ranged from 30° to 40° below zero F., and they were below freezing over practically all southern districts. In many sections the temperatures during this period were the lowest ever observed in March.

As a whole, the month was warmer than normal over most northern and central districts from the Rocky Mountains westward, and it was slightly cooler in the Southern States and generally to westward of the Rocky Mountains. (See Chart IV.)

PRECIPITATION.

Rains were frequent and occasionally heavy in the central and southern districts east of the Mississippi River and over portions of the Pacific Coast States, and heavy snows fell at different periods in the northeastern States, also locally in the Lake region, the Dakotas, and in many of the mountain districts of the West.[2]

The total precipitation for the month (see Chart V) was above normal over the East Gulf and South Atlantic States, except in Florida, generally over the central valleys and eastern portions of the Great Plains and over the Plateau and Pacific Coast States. Small areas of deficient precipitation appear over the upper Ohio drainage, and in portions of the Middle Atlantic States, over Florida, and the west Gulf States, and generally in the Rocky Mountain region. In some Pacific coast districts the fall during the month was more than had occurred during the entire season preceding.[2]

SNOWFALL.

Measurable quantities of snow fell over all districts save in portions of the Southeastern States, over the greater part of Texas and Oklahoma, and along the immediate Pacific coast. (See Chart VIII.) The deep snow covering New England and the northern portions of New York at the end of February was further augmented during March by heavy falls on the 5th and 6th, which again blocked transportation, barely recovered from the heavy snow and ice storms so frequent during the preceding months. Some heavy falls of snow occurred in the Lake region, and during the storm of the 15th and 16th over the Dakotas and surrounding States heavy snow fell over large areas, and much loss to stock and derangement of transportation resulted on account of the accompanying and following high winds and severe cold.

Over other districts east of the Rocky Mountains the snowfall was generally light. In the Rocky Mountains considerable snow occurred, particularly in Colorado, where the total depth of new snow was in some cases more than five feet. In the mountains of eastern California and the adjacent portions of Nevada and Oregon heavy snows occurred during the month, greatly relieving the outlook for a disastrous shortage of water during the coming summer. On the whole the snow over the western mountain districts was sufficient to justify a general estimate of near the normal supply of water for irrigation and other purposes, except in some portions of California where the lack of snow during the winter months has not yet been made good, and the generous falls during March are not in condition to remain unmelted till late in the season as is the case when the snow falls earlier in the winter.[2]

RELATIVE HUMIDITY.

From the Rocky Mountains eastward the relative humidity was everywhere less than normal, save for scattered small areas in New England, the upper Lake region, and portions of the Dakotas, In the Plateau region and the adjacent portions of the Pacific Coast States the relative humidity was generally less than normal, though usually to only a small per cent, except in portions of Arizona and New Mexico. In the middle Plains and thence eastward to the Appalachian Mountains there was a large deficiency in the relative humidity, ranging from 10 to 15 per cent or more, over wide areas despite the fact that precipitation during the month was frequent and at times heavy in this region.

A rather unusual occurrence of low vapor pressure and low relative humidity was observed about noon of the 28th, over a narrow strip from eastern Missouri northward over central Illinois. The relative humidity ranged from 11 per cent at St. Louis, Mo., to 16 and 18 per cent, respectively, at Springfield and Peoria, Ill., in some cases the lowest readings ever observed.

As the humidities were much higher on all sides, the extraordinary dryness of this strip must have been the result of a rapid downward movement of air from high and dry altitudes, immediately in the rear (west) of the belt of wind convergence where there were severe thunderstorms with tornadoes.

LOCAL STORMS.

Numerous local and severe widespread storms occurred during the month, descriptions of which will be found in other portions of this and the next issues of the REVIEW.

[2] Cf. "The drought in California," p. 156-157.

STORMS AND WARNINGS—WEATHER AND CROPS.

STORMS AND WEATHER WARNINGS.

By H. C. FRANKENFIELD, Supervising Forecaster.

[Washington, May 4, 1920.]

The month of March was characterized by persistent and marked storm activity, and there were very few days, indeed, without some considerable portion of the country under the influence of severe weather conditions.

There were four major storms that moved across the United States, and two others that were only a little less pronounced. The four major storms were attended by widespread rains and snows, gales, and by subsequent low temperatures. A somewhat detailed description of each will be given.

Storm of March 1–7.—This storm was first noted on the morning of March 1 off the central California coast, marked high pressure prevailing at the time over Alaska. During the succeeding 48 hours the LOW developed rather slowly to the eastward, while the Alaska HIGH moved across the United States and Canadian Northwest, both with steadily increasing intensity, so that on the morning of March 3 the storm center was over southwest Kansas (Dodge City, 29.48 inches), and the crest of the HIGH over northern Saskatchewan (Battleford, 30.60 inches). East of the Mississippi River pressure was also high, decidedly so over the Northeast. At this time the first warnings were issued in the Washington district, namely, small-craft warnings for the middle gulf coast for fresh, possibly strong southeast winds, and advisory warnings for open ports on Lake Michigan for fresh, possibly strong, east to north winds with snow.

On the evening of March 3 the storm center was over the upper Mississippi Valley, with abnormally high pressure and rapidly falling temperature to the northwestward, and at 10:30 p. m. SE. storm warnings were ordered along the middle Gulf coast. On the morning of March 4 the region of greatest storm activity extended in a narrow trough from Louisiana to Lake Michigan, with three distinct centers, one over southern Mississippi, one over central Illinois, and a third over southern Lake Michigan, pressure continuing to rise over the Northwest with very low temperatures. The advisory warnings for Lake Michigan were repeated in more emphatic form, gales, snow, and much colder weather being forecast, and the forecasts for nearly all sections east of the Mississippi River carried warnings of strong winds. At 11:30 a. m. NW. storm warnings were ordered displayed generally along the Gulf coast from Bay St. Louis, Miss., to Carrabelle, Fla., strong north winds with clearing and much colder weather being forecast. Cold-wave warnings were also ordered for the upper Lake Region, west Tennessee, and the East Gulf States, and warnings of frost for southern Florida and of freezing temperatures for the remaining southern districts.

Special 1 p. m. observations showed a slow eastward movement of the storm, and at 4 p. m. SE. storm warnings were ordered displayed along the Atlantic coast from Eastport, Me., to Jacksonville, Fla., winds to become strong from S. and to shift to NW. by the night of the 5th. NW. warnings had also been ordered on the East Gulf coast from Cedar Keys to Tampa, Fla.

After the morning of the 4th the storm moved more rapidly, and on the following morning it extended from the Carolina coast to eastern Ontario with the principal center over the southern section. The SE. warnings were changed to NW. from Jacksonville, Fla., to Portsmouth, N. H., and those at Cedar Keys and Tampa, Fla., lowered. At 3 p. m. of this day (5th), the following advisory warning was sent to stations and others interested:

> Pressure continues to fall rapidly at coast stations. Center of disturbance near Cape Henry, apparently moving northeast. Will cause severe gales, becoming north and northwest over steamer lanes for the next 36 hours. Much colder.

Cold-wave warnings were also ordered on the morning of the 5th for the Atlantic States and western New York, and frosts forecast as far south as the southern limits of the Florida mainland. In the evening the warnings on the south Atlantic coast were lowered, and on the morning of the 6th, with but a single storm center off the southern New England coast (Block Island, R. I., 28.82 inches), the NW. warnings were continued from Delaware Breakwater northward. Severe gales were in progress at the time (Block Island, 60 mi./hr.), and heavy snows had been falling over the Middle Atlantic States, continuing over New York and southern New England. Cold-wave warnings were ordered for Maine and eastern New York, and warnings of heavy frost, or freezing temperatures, throughout the South. At 8 p. m. of the 6th the barometer read 28.72 inches at Eastport, Me., with gales continuing from New York City northeastward, New York reporting a maximum velocity of 72 mi./hr. from the NW. On the morning of the 7th the storm center was beyond New Brunswick, the gales had subsided, and high pressure and low temperatures prevailed throughout the entire country east of the Rocky Mountains, except over the Northeast. The last warnings in connection with this storm were then issued, forecasting another night of freezing temperatures and heavy frosts throughout the South.

All warnings issued during this storm were fully justified by the subsequent occurrences, and marine disasters were remarkably few.

Storm of March 9–15.—The second great storm apparently originated during March 8 over Nevada, and by the following morning a moderate LOW had formed. For two days it moved slowly eastward with increasing intensity, and on the morning of the 11th it was central over NW. Kansas (Goodland, 29.48 inches). Pressure was then quite high over the Atlantic States and the north Atlantic Ocean (Bermuda, 30.52 inches), and at 11 a. m. SE. storm warnings were ordered along the Gulf coast from Carrabelle to Pensacola, Fla., and small- craft warnings over the Mobile, Ala., district. After the morning of the 11th, the LOW moved more rapidly, and reached central Illinois by evening with rapidly rising pressure to the westward and northwestward. Advisory warnings were then sent to open ports on Lake Michigan for moderately strong NW. winds during the next day with lower temperatures and rain turning to snow. The storm path now turned sharply to northeast with the usual increase in intensity attending such movement, and on the morning of March 12 the storm was central over Georgian Bay (Alpena, Mich., 29.22 inches), with strong NW. and N. winds and snow on Lakes Superior and Michigan.

A slight secondary disturbance had also appeared over NE. Texas on the evening of the 11th, and began to move eastward, and a tornado occurred in southwest

Missouri (see p. 158, above). At 11 a. m. SW. storm warnings were ordered along the Atlantic coast from Eastport, Me., to Hatteras, N. C., for strong S. and SW. winds, shifting to NW. on Saturday, March 13. By 8 p. m., March 13, the primary storm center had passed beyond Newfoundland, while the secondary one, which had reached the southern Appalachian region on the previous evening, had also made a turn to the northeastward, and was over New Jersey with a marked increase in energy (Philadelphia, Pa., Atlantic City, N. J., and New York City, 29.34 inches). General rains were falling but there had not yet been any strong winds north of Hatteras. At 11 a. m. NW. storm warnings were ordered south of Hatteras as far as Jacksonville, to be lowered at sunset, and the SW. warnings to northward changed to NW., winds of gale force being forecast. Cold-wave warnings were also ordered for portions of interior New England and the Middle Atlantic States, and frost warnings to southward as far as extreme northern Florida. At 8 p. m. March 13 the storm center was near the western Maine coast (Portland, Me., 28.90, and Boston, 28.92 inches), and by the following evening it had reached Newfoundland. On the morning of March 14 the NW. storm warnings were ordered continued from Point Judith, R. I., to Eastport, Me., and by the morning of the 15th the gales had subsided.

All storm warnings ordered for this storm were fully verified, but the cold-wave warnings were only partially verified, although there was a decided fall in temperature.

Storm of March 13–17.—The third great storm. Pressure had remained much below the normal over the Aleutian Islands since March 4, and on the morning of the 13th another offshoot from the general depression was central over the north coast of Washington. It moved southeastward at a fair rate of speed, but with rapidly increasing development, and by the evening of March 14 it had reached western Nebraska (North Platte, 28.90 inches), the general depression covering the entire interior district from the Mississippi Valley westward. At 9:30 p. m. advisory warnings were sent to open ports on Lake Michigan for moderately strong winds on the following day, and at 11 p. m. SE. storm warnings were ordered along the Gulf coast from Bay St. Louis, Miss., to Carrabelle, Fla., for strong S. winds during the next 36 hours. During the night of the 14th–15th the storm track turned abruptly to the north-northeastward, and on the morning of the 15th it was over eastern South Dakota (Moorhead, Minn., 28.68 inches). Advisory warnings were repeated to open ports on Lake Michigan, and included therein were forecasts of strong NW. winds on the following day with rain and snow and falling temperatures. At noon of the 15th SW. storm warnings were ordered along the Atlantic coast from Provincetown Mass., to the Virginia Capes, strong SE. and SW. winds being forecast. At 8 p. m. the barometer at Moorhead, Minn., read 28.56 incnes, and on the following morning the storm center was northwest of Lake Superior (Duluth, Minn., and Port Arthur, Ontario, 28.94 inches). Advisory warnings were again sent to open ports on Lake Michigan, and the SW. warnings continued on the Atlantic coast. At 4 p. m. the SW. warnings were extended northward to Eastport, Me. The storm center continued its northeastward course with increasing velocity of progression, passing south of and near James Bay, and on the morning of the 16th it was over New Brunswick. By evening it had passed beyond St. Johns, F.

All warnings issued in connection with this storm were verified.

Storm of March 26–30.—Fourth great storm. This storm was a secondary development of a primary LOW to the northward, and was first noted over southwestern Utah on the morning of March 26. It moved almost due eastward during the first 36 hours, and at 8 p. m., March 27, it was central over western Kansas (Dodge City, 29.16 inches). Advisory warnings for strong SE. winds were at once sent to open ports on Lake Michigan, and repeated on the following morning, a shift of the strong winds to NW. with rain or snow and lower temperatures being forecast. The storm center by this time had turned to north-northeastward with steadily increasing intensity, and was over extreme eastern Nebraska (Sioux City, Iowa, 28.96 inches), with a great depression covering the entire center of the country. After the receipt of special noon observations, SW. storm warnings were ordered along the Atlantic coast from Eastport, Me., to Charleston, S. C., strong winds shifting to SW. being forecast. The storm was then central over southern Minnesota (Minneapolis, 28.96 inches), and strong shifting gales had occurred to the southward and southwestward. It was only a few hours after this time that the disastrous tornadoes occurred over portions of Illinois, Indiana, Ohio, Michigan, Alabama, and Georgia, causing the loss of 88 human lives, and property destruction to the amount of about $10,000,000. Detailed reports of these tornadoes will be found in the April issue of this REVIEW.

At 8 p. m., March 28, the storm center was over northern Wisconsin (Green Bay, Wis., and Duluth, Minn., 28.98 inches), and by the following morning it was north of and near Lake Superior (White River, Ontario, 28.88 inches), with a more rapid northeastwardly movement. A more moderate secondary LOW appeared during the night preceding over West Virginia, and by 8 p. m., March 29, it was off the north coast of Massachusetts with much increased energy. The warnings from New York City to Eastport, Me., were then changed to NW., while those to the southward were allowed to expire.

On the morning of the 30th, the LOW center was over the Gulf of St. Lawrence, with still lower pressure (Father Point, Quebec, 29.30 inches), and by evening it was over Newfoundland.

All warnings issued for this storm were justified by subsequent occurrences, except in a few localities.

Storm of March 15–21.—This storm, while also characterized by abnormally low pressures, did not cause any strong winds of consequence over the district, except along the northern New England coast, and its failure in this respect was doubtless due to the absence of high pressure and low temperatures immediately preceding or following. The storm came from the north Pacific Ocean, and was definitely charted on the evening of March 15 over southwest Oregon (Roseburg, 29.40 inches). The great storm that had immediately preceded was then over northwest Minnesota. The Oregon LOW moved southeastward to southern Utah, thence east-northeastward by way of northwest Kansas, reaching northwest Iowa on the evening of March 18 (Sioux City, 29.30 inches).

The usual advisory warnings were then sent to open ports on Lake Michigan. After this time the storm center moved more directly eastward, and at 1 p. m., March 19, was over northeast Ohio (Erie, Pa., 29.36 inches). At 3:30 p. m. SE. storm warnings were ordered along the Atlantic coast from Portland, Me., to Delaware Breakwater, Del., and SW. warnings to southward as far as Hatteras, N. C. By evening the storm had divided into two distinct sections, one over western New York and the other over southwestern Virginia, with a slight

secondary over eastern Maryland. Both the main sections moved rapidly northeastward during the night, and on the morning of the 20th, the Virginia one was over the Island of Nantucket (29.18 inches). By evening it had passed over Newfoundland, and in the meantime the northern section had disappeared.

As stated above, no strong winds occurred, except along the Maine coast. There were, however, some very heavy snows over portions of New York and New England.

Storm of March 24–27.—On the morning of March 24 a well-defined LOW extended in the form of a narrow trough from eastern New Mexico to southern Minnesota, with a center of disturbance at each end, the northern one disappearing to the northward of Lake Superior during the succeeding night. On the morning of March 25 the southern LOW was central over Oklahoma (Altus, 29.14 inches), and SE. storm warnings had been ordered on the previous evening along the Gulf coast from Bay St. Louis, Miss., to Cedar Keys, Fla. Orders were issued at 3 p. m., March 25, to change these warnings to SW. at sunset, and SW. warnings were also ordered on the Atlantic coast from Jacksonville, Fla., to Charleston, S. C. At 8 p. m. the center of the storm was over SE. Iowa (Keokuk, 29.02 inches), and advisory warnings for strong winds and rain were sent to open ports on Lake Michigan. By the evening of March 26 the storm center was northeast of Lake Superior, and on the morning of March 28, it was north of Newfoundland with undiminished intensity.

The warnings issued on the 24th and 25th for the Gulf coast and the Jacksonville-Charleston section of the Atlantic coast were verified, except on the Atlantic coast, where only fresh winds occurred.

Still another severe storm appeared during the 29th north of British Columbia and developed to the southeastward. This storm will be discussed in the MONTHLY WEATHER REVIEW for April, 1920. The SE. storm warnings ordered at 3 p. m., March 25, on the New England coast were ordered as a matter of precaution, as a disturbance was moving northward over the western Atlantic Ocean, only a short distance from the coast, and its intensity was problematical. No strong winds followed, and the warnings were unnecessary.

WARNINGS FROM OTHER DISTRICTS.

Chicago, Ill., forecast district.—The month was marked by the movement in rapid succession of a remarkable series of low-pressure areas across this forecast district. The barometer was abnormally low in most of the storm areas. As the disturbances advanced they were attended by general rains and high winds and even gales.

The storm which crossed the district during the 3d and 4th was the only one that was followed by a well-marked cold wave, the HIGHS not following the LOWS in the usual order with marked changes in temperature.

The disturbance which advanced eastward across the Rockies on the 2d and reached Kansas on the 3d was one rather of the winter type, and by the evening of the 4th it had crossed the Upper Lake Region. Snow was general on its northern and western sides, with strong winds and falling temperature. Warnings to live-stock interests were issued on the morning of March 2 to South Dakota, Nebraska, and Wyoming points. Additional warnings were sent to Nebraska on the morning of the 3d and to Kansas and west Missouri. The messages contained advices of snow, cold weather, and strong northwest winds. Cold-wave warnings were also issued on the 3d to the Central Plains States, and they were extended on the morning of the 4th to Illinois and a portion of Wisconsin. These warnings, as well as the advices to stock interests, were fully verified, and it is believed that transportation and stock were protected from the severe conditions which followed. The cold was persistent for several days following the passage of this storm, temperatures being particularly low in the Northwest. A reading of -32° was reported at Billings, Mont.

Beginning on the 10th, the weather conditions became especially active. The storm which passed across the district on the 10th and 11th covered a wide area, but the barometer readings were not especially low. However, a few days later, in the storm which crossed over the more northerly States on the 14th to 16th, the pressure was very low, 28.56 inches being reported at Moorhead, Minn.

While the pressure in the following two storms was also low, it was not until the 28th that the reading again fell below 29 inches. On the morning of that day the barometer at Sioux City, Iowa, registered 28.96 inches. In the southeast quadrant of this storm, far from the center, in northern Illinois, three distinct tornadoes developed, which caused damage amounting to $3,150,000, 225 houses were wrecked, and 28 lives were lost, and 300 injured.

There were seven storms in all which crossed the district, and each one was attended by more or less severe gales. Generally speaking, it was probably the windiest month in this forecast district for a long period of years. Warnings of the gales were given in advance of these storms to the vessel interests on Lake Michigan maintaining winter navigation.

Warnings of snow and colder, with strong northwest winds, were sent to the live-stock interests on the morning of the 11th to points in Kansas and west Missouri, and on the morning of the 17th to Wyoming and west Nebraska. The conditions following these warnings were not as severe as those of the storm during the early days of the month, but nevertheless the warnings were justified.—*H. J. Cox.*

New Orleans Forecast District.—Storm or small craft warnings were issued for the Texas coast on the 3d, 11th, 14th, 24th, and 27th, and for the Louisiana coast on the 4th and 24th. These warnings were generally justified. No general storm occurred without warnings.

A cold wave overspread the district during the 3d, 4th, and 5th, for which timely warnings were issued. No cold wave of any importance occurred without warning.

Five weather warnings were issued as occasion required.—*I. M. Cline.*

Denver Forecast District.—The month was characterized in the Denver Forecast District by abnormally low temperature and windy weather. An unusually large number of deep storms from the Pacific coast crossed the district, causing frequent serious delays in telegraphic service and some interruption to railroad traffic in the mountain districts. Some winter grains were uncovered in eastern Colorado by strong winds. As is usual in storms that cross the mountains, an excess of precipitation occurred on the western slope and a deficiency in the districts east of the mountains. Record-breaking cold weather prevailed in eastern Colorado in the fore part of the month, an anticyclone of marked intensity spreading

slowly southward along the eastern slope, followed by several days of severe cold weather for the season of the year. Cold wave warnings were issued for eastern Colorado on the morning of the 3d. The warnings were verified in the greater part of the area for which the warnings were issued. However, still lower temperatures occurred in eastern Colorado on the mornings of the 6th and 7th, several stations reporting the lowest temperatures of record for March.—*Frederick W. Brist.*

San Francisco Forecast District.—The pressure distribution over the Pacific Slope during March showed a marked change from that of the two preceeding months. The hitherto prevalent high areas over the Rocky Mountain and Plateau regions gave way to frequent low areas moving in over British Columbia, and the Pacific HIGH moved southward and impinged on the southern Oregon and California coasts.

This pressure distribution was nearer the normal seasonal condition than had obtained heretofore this winter and precipitation occurred oftener and in greater amounts throughout this district. In eastern Oregon, western Idaho, northern Nevada, and California, except on the extreme north coast, the precipitation was above normal, the excess being greatest in the San Joaquin valley and southern California. In those sections where the precipitation was below the average, the amounts were greater than in either of the two preceding months. The snowfall on the ground in the mountain regions remains much below the average.

The temperature was generally slightly below normal in all sections, and there were no marked warm or cold spells.

On 11 days warnings were issued for light to heavy frosts in portions of California. The warnings were generally verified, but the frosts were not severe enough to cause serious damage.

Storm warnings were issued 15 times during the month and in most instances were verified.

On the 21st and 22d frequent reports were received by radio from the S. S. *Manoa*, at that time in a severe storm about 500 to 600 miles off the central California coast. The reports were of great assistance in determining the extent and probable duration of the storm at that time making its appearance on the coast.—*G. H. Willson.*

RIVERS AND FLOODS, MARCH, 1920.

By ALFRED J. HENRY, Meterologist in Charge.

[Weather Bureau, River and Flood Division, Washington, Apr. 30, 1920.]

March is preeminently the month of maximum flood frequency east of the 100th meridian and the current month was no exception, although it may be said that there was no severe and widespread flood in any part of the country.[1]

At the beginning of the month the snow cover in the Northern Middle Atlantic States and New England was of very considerable depth and by reason of the prevailing low temperature of the preceding months it was well packed and contained a large water content. The presence of this great snow blanket which ranged from 10 to 15 inches in depth over northern Pennsylvania and New York increasing to between 2 and 3 feet over New England and the near approach of thawing weather was the cause of some alarm in many localities. As often happens in the case of well-packed snow, the flood menace is not great; in this case the flood waters from the melting snow and moderate rains passed down the streams generally without special incident.

There were rather frequent short periods of rain with temperatures above freezing in northern watersheds but at no single time did the elements combine to cause disastrous floods.

The rivers of eastern Pennsulvania reached flood stage on the 5th and 6th as the result of thawing weather and rain coupled with the breaking up of the ice. The mills of Manayunk, Philadelphia, were obliged to remove perishable goods from the first floor of their establishments and to suspend operations for two days on account of high water. About a week later a short spell of warm weather attended by rain started a general break up of the ice in the streams of eastern New York and eastern Pennsylvania. Many ice gorges were formed and there was more or less local flooding as a result. The Hudson at Albany and Troy passed above the flood stage on several occasions during the month and remained close to flood stage at the end of the month.

The ice broke up in the Connecticut on the closing days of the month, starting on White River on the 25th. There was more or less flooding of the lowlands and damage that could not be prevented. The Connecticut at Hartford remained in flood until April 9.

The Susquehanna of Pennsulvania and New York after an unusually long icebound period began to break up in the upper tributaries in Pennsylvania as early as the 6th and was clear of ice down to Harrisburg by the 13th. The principal flood occurred on the 13th and 14th.

Moderate rain floods occurred in the streams of the South Atlantic and East Gulf drainage, also on the upper Trinity of the West Gulf drainage.

In the Great Lakes drainage the majority of the streams in lower Michigan and northern Ohio and Indiana reached flood stages during the period 12th to 17th.

In the upper Mississippi drainage in Wisconsin and Minnesota the streams did not attain flood stages until near the end of the month. The heavy rain of the 25th and 26th, together with the runoff from melting snow, caused a sharp rise in the streams, which crested with slightly above flood stages on the closing days of the month. The crest of the flood in the upper Mississippi on the 31st was below Reeds, Minn.

The Mississippi proper.—As above indicated the spring rise had set in at the close of the month and there was also a moderate flood in the river below the mouth of the Missouri. The upper tributaries of the Ohio were in flood, some as early as the 6th and practically all of them again on the 13th. By the time flood waters of the last named had reached the lower reaches of the streams heavy rains over Kentucky and Tennessee caused floods in the rivers of those States which synchronizing with high water in the main river as well as in the Mississippi below St. Louis resulted in a stage of 51.4 feet on the Cairo gage on the 31st. On that date the Mississippi was in flood from below Reeds, Minn., to Arkansas City, Ark. The subsequent history of this Mississippi flood belongs to the record of April.

[1] For note on conditions in the West, see "The snowfall in the Western States, winter 1919-20, p. 156.

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The usual details as to flood stages and the estimated money loss due to floods may be found in the tables below:

Estimates money loss due to floods.

River or district.	Tangible property, bridges, railroads, etc.	Crops prospective.	Live stock.	Suspension of business.	Value of warnings.
Connecticut	$260,000		500	$1,000	$3,500
Hudson	3,000				
Susquehanna	100,000				
Grand (Michigan)	1,250				
Saginaw	3,700			500	
Wisconsin	10,500			28,305	30,000
Ohio:					
Pittsburgh	[1] 25,000				
Louisville	10,000				
Wabash		4,000	2,000		250,000
Arkansas:					
Fort Smith	40,000	8,000			8,000
Trinity:					
Dallas	4,500	6,000			
Peedee:					
Charleston				2,000	5,000
Total	457,950	18,000	2,500	31,805	296,500

[1] Suspension of business and cleaning up.

TABLE I.—*Flood stages March, 1920.*

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
ATLANTIC DRAINAGE.					
Connecticut:	*Feet.*			*Feet.*	
White River Junction, Vt.	13	25	(**)	17.6	26
Bellows Falls, Vt.	12	28	28	13.0	28
Hartford, Conn.	16	27	(**)	22.5	30
Holyoke, Mass.	9	29	29	9.8	29
Hudson:					
Troy, N. Y.	15	14	14	16.1	14
Do	15	18	18	16.5	18
Do	15	27	(**)	18.3	27
Albany, N. Y.	12	18	19	13.5	18
Do	12	27	29	14.0	27
Castleton, N. Y.	10	27	28	10.3	27
Stuyvesant, N. Y.	9	26	27	9.7	27
Mohawk:					
Tribeshill, N. Y.	16	13	13	21.6	13
Do	16	27	27	16.8	27
Delaware (East Branch):					
Fishs Eddy, N. Y.	10	13	13	18.0	13
Do	10	27	27	10.7	27
Lehigh:					
Allentown, Pa.	14	5	5	16.9	5
Schuylkill:					
Reading, Pa.	12	7	7	15.6	7
Susquehanna:					
Oneonta, N. Y.	12	17	18	12.9	17
Do	12	25	(**)	14.7	27
Bainbridge, N. Y.	11	13	20	14.4	18
Do	11	24	30	15.3	28
Binghamton, N. Y.	14	27	28	14.6	28
Towanda, Pa.	16	13	13	16.3	13
Wilkes-Barre, Pa.	20	13	14	25.6	13
Harrisburg, Pa.	17	13	14	20.1	13,14
Chemung:					
Corning, N. Y.	16	12	13	17.2	13
Unadilla					
New Berlin, N. Y.	8	26	31	12.0	27
Susquehanna (West Branch):					
Williamsport, Pa.	20	13	13	20.4	13
Tar:					
Greenville, N. C.	13	9	11	13.6	10
Peedee:					
Cheraw, S. C.	27	14	14	27.6	14
Santee:					
Ferguson, S. C.	12	(*)	1	12.4	1
Do	12	8	(**)	13.7	18,19
Rimini, S. C.	12	6	(**)	15.7	18
Wateree:					
Camden, S. C.	24	14	14	24.0	14
Congaree:					
Columbia, S. C.	15	13	13	15.1	13
Broad:					
Blairs, S. C.	15	30	30	15.1	30
Saluda:					
Pelzer, S. C.	7	29	29	7.2	29
Chappels, S. C.	14	13	15	16.8	14
Do	14	30	(**)	17.0	31
Broad:					
Carlton, Ga.	11	13	13	14.0	13
Do	11	29	30	15.5	30
Oconee:					
Milledgeville, Ga.	22	18	18	22.6	18
Do	22	29	30	26.5	30

* Continued from February.

TABLE I.—*Flood stages March, 1920*—Continued.

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
ATLANTIC DRAINAGE—continued.					
Ocmulgee:	*Feet.*			*Feet.*	
Macon, Ga.	18	17	18	19.9	18
Do	18	29	30	20.5	30
Abbeville, Ga.	11	19	28	15.2	23
Lumber City, Ga.	15	26	28	16.2	26
EAST GULF DRAINAGE.					
Apalachicola:					
Blountstown, Fla.	15	21	26	16.5	23
Do	15	30	31	15.1	30
River Junction, Fla.	12	14	(**)	20.1	22
Flint:					
Woodbury, Ga.	10	18	18	12.0	18
Do	10	30	30	11.2	30
Montezuma, Ga.	20	20	20	20.2	20
Albany, Ga.	20	24	26	22.9	24
Chattahoochee:					
Alaga, Ala.	30	20	22	34.0	21
Alabama:					
Montgomery, Ala.	35	19	23	41.9	21
Selma, Ala.	35	19	26	44.9	22
Do	35	31	(**)	35.7	31
Cahaba:					
Centerville, Ala.	25	18	18	28.3	18
Tombigbee:					
Aberdeen, Miss.	33	14	16	36.2	15
Demopolis, Ala.	39	17	(**)	56.4	27
Black Warrior:					
Tuscaloosa, Ala.	46	18	21	51.6	20
Pearl:					
Jackson, Miss.	20	14	(**)	26.5	27
WEST GULF DRAINAGE.					
Trinity:					
Fort Worth, Tex.	20	25	25	27.7	25
Dallas, Tex.	25	25	28	35.3	26
Trinidad, Tex.	28	31	31	31.3	31
GREAT LAKES DRAINAGE.					
St. Joseph:					
Montpelier, Ohio.	10	6	8	12.4	7
Do	10	12	14	12.2	13
Saginaw:					
Saginaw, Mich.	19	16	20	20.2	18
Pine:					
Alma, Mich.	6	12	12	7.5	12
Do	6	16	19	8.5	16
Chippewa:					
Chippewa Falls, Wis.	16	27	27	16.3	27
Mount Pleasant, Mich.	12	12	17	13.2	12
Grand:					
Eaton Rapids, Mich.	6	12	14	6.4	12,13
Lansing, Mich.	11	13	14	11.4	13
Grand Ledge, Mich.	6	12	18	11.4	14
Ionia, Mich.	21	14	17	21.6	17
Lowell, Mich.	15	15	18	16.5	17
Grand Rapids, Mich.	11	16	21	14.9	16,17
East Lansing, Mich.	8	12	17	10.7	13
Cedar:					
Williamston, Mich.	10	12	15	10.6	12
HUDSON BAY DRAINAGE.					
Red River of the North:					
Grand Forks, N. Dak.	35	28	31	35.8	29
MISSISSIPPI DRAINAGE (OHIO BASIN).					
Ohio:					
Pittsburgh, Pa.	22	13	14	25.2	13
Beaver Dam, Pa.	30	13	15	36.5	14
Marietta, Ohio.	33	15	16	34.8	15
Point Pleasant, W. Va.	40	17	22	45.0	20
Dam No. 29, Normal, Ky.	50	20	22	53.5	21
Dam No. 30, Oliver, Ky.	52	21	21	52.5	21
Portsmouth, Ohio.	50	20	22	52.9	21
Maysville, Ky.	50	20	23	52.0	22
Cincinnati, Ohio.	50	19	24	54.6	22
Madison, Ind.	46	21	24	47.8	23
Louisville, Ky.	28	20	25	31.5	23
Cloverport, Ky.	40	19	27	46.7	23,24
Henderson, Ky.	33	18	(**)	41.2	25,26
Evansville, Ind.	35	18	(**)	42.8	24,25
Mount Vernon, Ind.	35	19	(**)	43.2	26
Shawneetown, Ill.	35	18	(**)	46.0	27
Paducah, Ky.	43	23	(**)	45.3	28
Cairo, Ill.	45	20	(**)	51.4	31
Allegheny:					
Olean, N. Y.	12	13	14	14.7	13
Warren, Pa.	12	13	14	13.8	13
Franklin, Pa.	15	13	14	18.6	13
Parkers Landing, Pa.	18	13	14	21.8	13
Mosgrove, Pa.	20	13	14	25.0	13
Freeport, Pa.	22	13	14	27.2	13
Lock No. 3, Springdale, Pa.	27	13	15	33.0	13
Herr Island Dam, Pa.	22	13	14	28.1	13

** Continued into April.

TABLE I.—*Flood stages March, 1920*—Continued.

River and station.	Flood stage.	Above flood stages—dates. From—	To—	Crest. Stage.	Date.
MISSISSIPPI DRAINAGE (OHIO BASIN)—con.					
Kiskiminetas:	*Feet.*			*Feet.*	
Saltsburg, Pa.	8	5	5	11.0	5
Do.	8	13	13	9.8	13
Stony Creek:					
Johnstown, Pa.	10	12	12	11.0	12
Beaver:					
Beaver Falls, Pa.	11	13	13	11.3	13
Shenango:					
Sharon, Pa.	9	12	14	13.2	13
Tuscarawas:					
Norris Point, Ohio.	8	5	7	10.1	6
Do.	8	13	16	9.4	13
Coshocton, Ohio.	8	13	14	9.6	13
Do.	8	17	17	8.1	17
Walhonding:					
Walhonding, Ohio.	8	5	6	10.6	5
Do.	8	12	13	10.0	13
Do.	8	17	17	8.0	17
Scioto:					
La Rue, Ohio.	11	4	6	12.0	5
Circleville, Ohio.	10	6	6	10.0	6
Do.	10	13	13	10.3	13
Kentucky:					
Beattyville, Ky.	30	20	20	30.0	20
Green:					
Lock No. 2, Rumsey, Ky.	34	20	29	38.8	26
Lock No. 4, Woodbury, Ky.	33	20	24	38.2	22
Wabash:					
Lafayette, Ind.	11	13	13	12.1	13
Do.	11	17	18	11.7	17
Mount Carmel, Ill.	15	15	28	20.0	22
White:					
Decker, Ind.	18	17	26	20.8	21, 22
East Fork—					
Shoals, Ind.	20	19	23	21.7	20
Big Pigeon:					
Newport, Tenn.	6	17	17	6.6	17
Tennessee:					
Knoxville, Tenn.	12	20	21	13.0	20
Riverton, Ala.	32	13	26	36.7	15
Holston (North Fork):					
Mendota, Va.	8	20	20	9.1	20
Clinch:					
Clinton, Tenn.	25	14	15	25.8	15
Duck:					
Columbia, Tenn.	30	14	14	31.0	14
Mississippi:					
Reeds, Minn.	12	29	(**)	12.3	30
Winona, Minn.	16	31	(**)	16.0	31
La Crosse, Wis.	12	29	(**)	13.8	31
Keokuk, Iowa.	14	29	(**)	14.4	30
Warsaw, Ill.	17	29	(**)	17.4	29
Hannibal, Mo.	13	27	(**)	16.6	30
Louisiana, Mo.	12	27	(**)	14.9	30
Quincy, Ill.	14	27	(**)	16.1	30
Grafton, Ill.	18	29	(**)	20.2	31
Alton, Ill.	21	28	(**)	24.5	31
Chester, Ill.	27	31	(**)	27.1	31
Cape Girardeau, Mo.	30	30	(**)	31.9	31
New Madrid, Mo.	34	20	(**)	40.0	31
Memphis, Tenn.	35	27	(**)	37.8	31
Helena, Ark.	42	27	(**)	45.5	31
Arkansas City, Ark.	42	27	(**)	46.4	31
Wisconsin:					
Merrill, Wis.	11	29	29	11.4	29
Wausau, Wis.	10	26	26	10.4	26
Do.	10	29	29	10.4	29
Knowlton, Wis.	12	26	(**)	17.5	27
Grand Rapids, Wis.	12	28	28	12.0	28
Portage, Wis.	14	29	(**)	14.9	31
Des Moines:					
Ottumwa, Iowa.	10	16	16	10.3	16
Do.	10	25	28	12.3	26
Illinois:					
Morris, Ill.	13	12	14	17.0	13
Do.	13	26	30	16.2	27
Peru, Ill.	14	8	9	14.7	9
Do.	14	12	(**)	20.5	29
Henry, Ill.	7	12	(**)	14.4	29, 30
Peoria, Ill.	16	14	(**)	20.8	30, 31
Havana, Ill.	14	15	(**)	17.1	31
Beardstown, Ill.	12	13	(**)	18.1	31
Pearl, Ill.	12	17	(**)	16.2	31

** Continued into April.

TABLE I.—*Flood stages March, 1920*—Continued.

River and station.	Flood stage.	Above flood stages—dates. From—	To—	Crest. Stage.	Date.
MISSISSIPPI DRAINAGE (OHIO BASIN)—con.					
Missouri:	*Feet.*			*Feet.*	
St. Charles, Mo.	25	28	(**)	26.4	30
Grand:					
Chillicothe, Mo.	18	26	(**)	26.9	30
Brunswick, Mo.	10	27	(**)	11.7	28, 29
Osage:					
Osceola, Mo.	20	27	28	21.5	28
Warsaw, Mo.	22	26	29	28.8	27
Tuscumbia, Mo.	25	27	30	28.5	29
Meramec:					
Steelville, Mo.	12	26	26	13.6	26
Pacific, Mo.	11	26	29	17.4	28
Glencoe, Mo.	15	29	29	16.5	29
Valley Park, Mo.	14	14	14	15.0	14
Do.	14	27	29	18.6	29
Bourbeuse:					
Union, Mo.	10	13	14	12.6	14
Do.	10	27	28	12.9	27
Ouachita:					
Arkadelphia, Ark.	18	26	27	20.0	27
Camden, Ark.	30	30	(**)	33.8	31
James:					
Huron, S. Dak.	9	15	(**)	15.6	28
Arkansas:					
Fort Smith, Ark.	22	28	29	22.9	28
Dardanelle, Ark.	20	29	30	20.9	29
Neosho:					
Fort Gibson, Okla.	22	27	28	24.5	27
Petit Jean:					
Danville, Ark.	20	26	29	24.6	26
White:					
Calico Rock, Ark.	18	26	29	30.2	26
Batesville, Ark.	23	26	30	34.0	27
Newport, Ark.	26	28	(**)	29.3	29
Georgetown, Ark.	22	28	(**)	24.2	31
Black:					
Black Rock, Ark.	14	5	9	17.0	5
Do.	14	12	(**)	20.9	27
Little:					
Whitecliffs, Ark.	28	28	29	29.1	28
Sulphur:					
Finley, Tex.	24	27	(**)	28.0	29, 30
Ringo Crossing, Tex.	20	26	30	28.0	26

** Continued into April.

MEAN LAKE LEVELS DURING MARCH, 1920.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., Apr. 6, 1920.]

The following data are reported in the "Notice to Mariners" of the above date:

Data.	Lakes.* Superior.	Michigan and Huron.	Erie.	Ontario.
Mean level during March, 1920:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	601.92	580.00	570.85	245.05
Above or below—				
Mean stage of February, 1920	+0.01	+0.05	+0.05	+0.04
Mean stage of March, 1919	+0.03	−0.73	−1.64	−0.96
Average stage for March, last 10 years	+0.28	0.00	−0.90	−0.62
Highest recorded March stage	−0.36	−2.95	−3.00	−2.76
Lowest recorded March stage	+1.26	+0.89	+0.02	+0.75
Average relation of the March level to—				
February level	.....	+0.1	+0.1	+0.2
April level	.....	−0.3	−0.6	−0.7

* Lake St. Clair's level: In March, 574 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, MARCH, 1920.

By J. WARREN SMITH, Meteorologist in Charge.

The weather during the first decade of March was very unfavorable for farm operations and the advance of vegetation in practically all sections east of the Rocky Mountains. Much damage was done by low temperatures in the Southern States and there was considerable snow and much stormy weather in northern districts, while dry weather was harmful in the southern Great Plains. It was too cold for winter wheat to make material advance in the principal winter-wheat belt, while lack of moisture and cold, high winds were detrimental in portions of the Great Plains. The seeding of spring grains was delayed by unfavorable weather.

The soil was too wet to work in central and eastern districts during most of the second decade of the month, but temperatures were more favorable in the South where crops slowly recovered from the effect of the damaging temperatures earlier in the month. Frequent rains, however, permitted of little preparation for cotton and corn planting in this area. Winter grains made better advance than during the first decade. Ranges improved in the West, and stock were benefited by milder temperatures, but more moisture was needed in the Southwest.

Vegetation made fairly rapid advance in southern and central districts during the last decade of the month, but it was rather cool in the West and considerable damage occurred to fruit in the far Southwest. The weather was more favorable for farm operations in most of the South, but general rains made the soil too wet for work in many central localities. Corn planting was behind the average season at the close of the month, but this work had progressed northward to southern North Carolina, Tennessee, and southeastern Missouri. Cotton planting was progressing slowly and germination was rather poor in most sections. Under the influence of warmer weather and ample soil moisture there was a widespread improvement in winter grains during the last decade of the month, but high winds were rather trying to winter wheat in the southern Great Plains. The seeding of spring grains made rapid progress west of the Mississippi River during this period but wet soil had caused considerable delay in districts to the eastward. Southern truck crops made satisfactory advance the latter part of the month and the comparatively warm weather caused good development in pastures and meadows.

CLIMATOLOGICAL TABLES.

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, March, 1920.

Section.	Temperature.								Precipitation.					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	52.6	−3.6	Evergreen	86	22	St. Bernard	10	8	7.27	+1.77	Dadeville	13.78	Silverhill	2.20
Arizona	49.4	−2.3	Mohawk	89	13	Bly Ranger Sta	0	28	1.45	+0.37	Sunflower Ranger Sta	4.30	" City	0.00
Arkansas	51.8	−1.5	2 stations	88	27	Nail	2	7	5.44	+0.53	Mt. Ida	8.57	Georgetown	1.93
California	49.3	−2.5	Blythe	88	13†	Portola	− 2	3	5.79	+1.05	Inskip	15.94	Brawley	0.00
Colorado	32.3	−1.8	2 stations	80	14	Dillon	−36	7	1.24	−0.06	Trout Lake	5.12	Buena Vista	0.00
Florida	63.0	−2.9	New Smyrna	97	28	Garniers (near)	21	1	1.20	−1.83	Mount Pleasant	3.86	Punta Gorda	T.
Georgia	53.5	−2.9	Brunswick	91	28	Blue Ridge	5	8	7.50	+2.62	Concord	15.33	Lumber City	3.05
Hawaii (February)	69.5	+1.2	Kahana	87	6†	Volcano Observatory	45	24	2.11	−4.36	Honomu	10.01	4 stations	0.00
Idaho	35.0	−1.0	Glenns Ferry	78	20	Stanley	−18	6†	2.10	+0.30	Musselshell	7.40	Hollister	0.26
Illinois	42.3	+2.6	3 stations	81	27†	Freeport	− 5	7	5.01	+2.00	New Burnside	7.88	Roberts	3.28
Indiana	42.6	+2.5	Shoals	82	28	2 stations	1	7	3.98	+0.29	Huntingburg	8.05	Connersville	1.91
Iowa	38.0	+4.7	2 stations	80	31	Inwood	−21	5	3.02	+1.25	Albia	5.70	Omaha	0.47
Kansas	45.7	+2.5	McPherson	87	31	New Ulysses	−21	7	1.69	+0.28	Walnut	6.01	4 stations	T.
Kentucky	46.3	+0.3	Bowling Green	88	27	Junction City	− 1	8	4.84	+0.18	Middlesboro	7.40	Jackson	3.15
Louisiana	58.1	−2.5	Calhoun	88	27	Kelly	17	1	3.22	−0.74	Monroe	7.17	La Rose	1.00
Maryland-Delaware	43.3	+1.2	Western Port, Md	85	26	Oakland, Md	− 1	1	3.14	−0.49	Crisfield, Md	4.61	Western Port, Md	1.91
Michigan	31.5	+2.4	Cassopolis	86	29	Humboldt	−40	6	2.70	+0.70	Whitefish Point	6.60	Mio	0.53
Minnesota	27.6	+1.7	2 stations	75	31	Hallock	−33	6	1.83	+0.72	Willmar	3.91	Fosston	0.05
Mississippi	55.0	−2.6	Anguilla	89	28	2 station	16	1†	5.79	+0.32	Agricultural College	12.14	Pascagoula	1.23
Missouri	44.6	+1.4	Caruthersville	86	27	St. Catherine	− 6	7	5.01	+2.09	Avalon	9.10	Tarkio	1.35
Montana	29.1	−1.5	Choteau	72	21	Foster	−37	6	1.08	+0.14	Haugan	4.01	Fort Shaw	T.
Nebraska	38.0	+2.5	Syracuse	83	31	Nenzel	−23	7	0.89	−0.21	Oakdale	3.21	Crete	0.04
Nevada	38.7	−1.5	Logandale	86	4	Tecoma	0	15	1.65	+0.62	Marlette Lake	6.00	Thorne	0.10
New England	32.8	+2.2	Waterbury, Conn	74	25	Pittsburg, N. H	−36	2	3.78	+0.05	Lewiston, Me	5.80	Madison, Me	1.73
New Jersey														
New Mexico	41.8	−1.9	Carlsbad	83	14	Senorito (near)	− 6	4	0.59	−0.28	Batemans Ranch	4.02	9 stations	0.00
New York	33.6	+2.0	York	78	26	Wanakena	−27	2	2.77	−0.29	Spier Falls	7.47	Lauterbrunnen	0.26
North Carolina	48.3	−1.1	Lumberton	88	29	Banners Elk	− 7	8	5.50	+1.13	Rock House	11.37	Henderson	2.62
North Dakota	22.4	−0.2	3 stations	67	30†	Hannah	−32	5	0.80	−0.03	Williston	2.18	2 stations	T.
Ohio	41.7	+3.0	2 stations	84	28†	Millport	− 4	1	2.72	−0.86	Green	5.27	Catawba Island	1.09
Oklahoma	51.3	−0.7	2 stations	87	25†	Hooker	−18	7	2.83	+0.63	Miami	8.13	Hurley	0.20
Oregon	41.0	−1.1	Cazadero	71	21	Crescent	− 6	17	3.55	+0.58	Tillamook	13.52	Hay Creek	0.18
Pennsylvania	38.7	+1.8	2 stations	80	25†	Milford	−11	8	2.83	−0.69	Freeland	9.70	Bethlehem	1.06
Porto Rico														
South Carolina	52.3	−2.5	Blackville	87	27	Walhalla	10	8	6.73	+2.83	Bowman	10.65	Paris Island	2.16
South Dakota	30.7	+0.3	Centerville	83	31	Pollock	−30	7	1.64	+0.89	Milbank	4.69	Eureka	0.27
Tennessee	48.4	−1.2	Kenton	86	28	Mountain City	− 5	8	5.40	+0.28	Yukon	9.51	Bolivar	2.28
Texas	57.3	−1.6	Eagle Pass	98	27	2 stations	− 4	7	1.37	−0.51	Sherman	7.78	5 stations	0.00
Utah	35.5	−2.5	St. George	76	13	East Portal	−25	19	2.42	+0.69	Silver Lake	12.46	Emery	T.
Virginia	45.6	+0.4	Runnymede	87	30	Burkes Garden	− 8	8	3.51	−0.29	Onley	5.72	Lassiter	1.45
Washington	41.4	−0.4	Lowden	72	20	Snyders Ranch	7	1†	2.98	+0.14	Forks	15.43	4 stations	T.
West Virginia	42.8	0.0	Huntington	83	25	Parsons	− 5	1	3.38	−0.51	Green Sulphur Springs	8.87	Harpers Ferry	1.40
Wisconsin	30.4	+1.7	Richland Center	76	31	Long Lake	−40	6	3.31	+1.76	Whitehall	5.76	Ashland	1.56
Wyoming	28.2	−2.5	2 stations	71	21†	Riverside	−41	6	0.99	−0.18	Snake River	4.12	Powell	0.01

† Other dates also.

TABLE I.—*Climatological data for Weather Bureau stations, March, 1920.*

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.													Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation.			Wind.					Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.								Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	° *F.*	° *F.*	° *F*		° *F*	° *F*		*F*	° *F*		° *F*					%	*In.*	*In.*		*Miles*							*0–10*	*In.*	*In.*
New England.							**35.0**	**+ 2.3**														**73**	**3.78**	**0.0**									**5.2**		
Eastport	76	67	85	29.79	29.88	−0.05	30.4	+ 1.5	54	24	38	− 4	2	23	29	28	24	76	4.36	+ 0.1	16	10,012	w.	56	ne.	20	8	7	16	6.4	14.2	T.	
Greenville, Me	1,070	6	....	28.68	29.88	.....	27.5	.....	68	24	38	−16	2	17	36	.....	.....	.....	2.85	.....	14	.....	.....	.....	.....	.....	14	3	14	....	18.2	18.0	
Portland, Me	103	82	117	29.80	29.93	− .03	34.6	+ 2.6	64	23	43	0	2	26	28	30	24	70	5.53	+ 1.8	19	8,062	sw.	48	nw.	6	16	2	13	4.8	13.6	T.	
Concord	288	70	79	29.63	29.95	− .05	33.8	+ 2.3	69	25	44	− 5	2	23	40	.....	.....	.....	2.43	− 1.0	11	4,879	nw.	40	nw.	6	14	6	11	4.9	10.0	0.0	
Burlington	404	11	48	29.48	29.94	− .06	30.9	+ 3.6	66	25	40	−13	2	34	22	.....	.....	.....	3.38	+ 1.6	11	11,225	s.	50	s.	16	8	9	14	6.3	25.3	T.	
Northfield	876	12	60	.....	29.95	− .05	29.5	+ 3.3	65	25	41	−19	2	18	41	.....	.....	75	2.52	− 0.3	11	7,189	s.	36	sw.	17	10	6	15	6.4	26.0	T.	
Boston	125	115	188	29.80	29.94	− .03	39.2	+ 4.2	72	24	48	10	2	30	29	34	28	67	3.72	− 0.4	10	9,491	sw.	51	nw.	6	14	8	9	5.0	11.0	0.0	
Nantucket	12	14	90	29.94	29.95	− .03	36.6	− 0.2	56	24	43	15	7	30	28	34	31	83	3.46	− 0.5	13	15,335	sw.	66	sw.	14	15	5	11	5.3	3.6	0.0	
Block Island	26	11	46	29.93	29.96	− .02	36.5	+ 0.6	57	24	43	13	7	30	28	34	32	85	4.38	0.0	11	16,894	sw.	72	nw.	6	18	2	11	4.5	1.4	0.0	
Providence	160	215	251	29.78	29.96	− .02	38.3	+ 2.6	66	23	48	9	2	29	32	34	28	70	3.66	− 1.0	13	12,241	nw.	72	nw.	6	16	7	8	4.4	4.3	0.0	
Hartford	159	122	140	29.80	29.98	− .01	37.7	+ 2.7	68	31	48	8	7	28	34	32	26	67	3.75	− 0.6	11	7,012	sw.	43	nw.	6	14	5	12	5.1	10.0	0.0	
New Haven	106	74	153	29.87	29.99	.00	37.5	+ 2.1	68	25	46	10	8	29	32	33	26	68	4.42	0.0	10	7,798	w.	36	nw.	6	17	5	9	4.2	8.4	0.0	
Middle Atlantic States.							**42.4**	**+ 2.3**														**68**	**3.09**	**− 0.7**									**4.6**		
Albany	97	102	115	29.86	29.98	− .03	34.0	+ 1.9	65	24	44	2	8	24	34	30	25	75	2.72	0.0	10	5,854	s.	28	s.	12	15	6	10	4.5	16.3	0.0	
Binghamton	871	10	84	29.03	29.98	− .04	36.0	+ 4.0	71	31	48	− 6	1	24	39	.....	.....	.....	2.72	+ 0.1	8	5,792	nw.	38	w.	7	7	14	10	5.7	14.3	0.0	
New York	314	414	454	29.65	30.00	.00	40.6	+ 3.1	69	31	49	12	7	32	30	35	27	61	4.16	+ 0.1	9	16,793	nw.	78	nw.	6	12	9	10	5.1	5.7	0.0	
Harrisburg	374	94	104	29.62	30.04	+ .01	41.0	+ 3.2	74	29	50	14	8	31	31	35	27	63	2.50	− 0.6	8	6,040	nw.	28	sw.	31	15	6	10	4.6	5.1	0.0	
Philadelphia	117	123	190	29.90	30.04	+ .02	43.8	+ 3.8	74	31	53	16	7	34	31	37	30	64	3.35	− 0.1	11	8,454	nw.	43	nw.	5	17	5	9	4.4	4.8	0.0	
Reading	325	81	98	.....	30.03	.....	41.4	.....	74	31	51	13	7	31	35	.....	.....	.....	4.51	− 1.0	10	6,703	nw.	35	n.	5	14	4	13	....	7.0	0.0	
Scranton	805	111	119	29.13	30.01	− .01	38.2	+ 3.3	73	25	49	8	7	28	37	33	27	71	3.50	+ 0.4	9	6,355	sw.	33	w.	13	11	9	11	5.4	9.9	0.0	
Atlantic City	52	37	48	29.97	30.03	+ .01	39.8	+ 1.0	62	27	47	15	7	33	25	36	31	74	3.36	− 0.4	10	6,850	sw.	36	s.	12	19	4	8	3.7	2.5	0.0	
Cape May	18	13	49	30.04	30.06	+ .05	41.6	+ 0.8	71	31	49	19	1	34	28	37	33	76	2.78	− 1.0	12	8,098	nw.	48	nw.	5	19	2	10	3.8	1.2	0.0	
Sandy Hook	22	10	57	29.98	30.01	.....	38.9	.....	66	31	46	13	7	32	28	35	32	81	3.43	.....	11	13,389	sw.	64	w.	6	14	8	9	4.7	6.3	0.0	
Trenton	190	159	183	29.80	30.01	.....	40.4	.....	71	31	51	12	7	30	34	36	30	68	3.81	− 0.2	11	10,420	w.	46	w.	13	13	8	10	4.9	6.8	0.0	
Baltimore	123	100	113	29.91	30.04	+ .01	44.8	+ 2.9	76	29	55	18	8	35	30	38	30	61	2.56	− 1.3	8	5,331	sw.	35	nw.	5	17	6	8	4.3	2.3	0.0	
Washington	112	62	85	29.92	30.04	.00	45.5	+ 3.3	77	29	56	17	6	35	33	38	31	61	2.39	− 1.5	9	6,549	nw.	48	nw.	5	14	5	12	4.8	1.2	0.0	
Lynchburg	681	153	188	29.30	30.06	+ .01	47.4	+ 2.0	77	27	59	14	8	36	43	40	34	65	2.82	− 1.0	10	6,846	nw.	40	nw.	13	13	11	7	4.3	0.3	0.0	
Norfolk	91	170	205	29.98	30.08	+ .05	50.0	+ 2.3	81	29	60	23	1	40	32	42	35	63	2.39	− 1.9	8	11,687	s.	60	nw.	5	14	7	10	4.5	0.2	0.0	
Richmond	144	11	52	29.91	30.07	+ .03	48.2	+ 1.3	79	29	60	16	8	36	36	42	37	72	3.11	− 0.6	9	6,681	sw.	39	nw.	5	15	6	10	4.6	T.	0.0	
Wytheville	2,304	49	56	27.66	30.09	+ .04	42.2	− 0.1	68	27	53	7	8	32	35	35	29	64	2.72	− 1.7	13	6,323	w.	35	w.	29	13	7	11	4.4	T.	0.0	
South Atlantic States.							**52.6**	**− 1.2**														**71**	**4.73**	**+ 0.5**									**4.9**		
Asheville	2,255	70	84	27.71	30.12	+ .06	43.8	− 1.1	72	27	54	8	8	34	36	37	30	67	5.65	+ 0.6	14	6,814	nw.	33	nw.	20	13	8	10	5.0	0.2	0.0	
Charlotte	779	55	62	29.23	30.08	+ .03	49.8	− 1.0	77	27	60	16	8	40	29	42	34	59	7.11	+ 2.5	12	5,111	sw.	31	nw.	13	13	7	11	4.9	T.	0.0	
Hatteras	11	12	50	30.07	30.08	+ .04	50.8	− 0.6	71	27	58	28	8	44	26	48	45	83	3.16	− 2.3	9	12,135	sw.	54	w.	13	10	12	9	5.2	0.0	0.0	
Manteo	12	5	42	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	
Raleigh	376	103	110	29.68	30.09	+ .04	50.6	+ 0.2	83	29	62	17	8	39	35	44	38	67	3.52	− 0.7	10	7,344	sw.	38	nw.	13	10	11	10	5.3	T.	0.0	
Wilmington	78	81	91	30.02	30.11	+ .06	53.2	− 0.5	79	27	62	24	8	44	29	47	44	75	4.11	+ 0.5	10	6,935	w.	45	sw.	13	15	7	9	4.4	0.0	0.0	
Charleston	48	11	92	30.05	30.10	+ .04	54.6	− 2.6	74	27	62	30	1	47	22	49	44	72	4.65	+ 0.9	9	8,956	ne.	40	w.	13	11	7	13	5.5	T.	0.0	
Columbia, S. C	351	41	57	29.72	30.11	+ .05	53.2	− 0.8	82	27	63	22	8	43	30	46	40	68	5.72	+ 2.0	11	6,025	s.	37	sw.	13	14	10	7	4.5	T.	0.0	
Greenville, S. C	1,039	113	122	28.96	30.07	.....	49.6	.....	76	27	59	16	8	40	28	42	35	64	8.26	.....	13	7,169	sw.	44	w.	13	15	4	12	4.6	0.0	0.0	
Augusta	180	62	77	29.90	30.09	+ .03	54.2	− 1.7	82	27	64	23	8	44	32	48	44	75	9.15	+ 4.3	10	5,262	s.	33	nw.	28	16	0	15	5.2	T.	0.0	
Savannah	65	150	194	30.04	30.12	+ .06	56.6	− 1.7	84	28	65	27	8	48	24	49	44	71	3.39	− 0.3	9	10,165	nw.	52	w.	13	12	7	12	5.3	T.	0.0	
Jacksonville	43	209	245	30.06	30.12	+ .06	59.5	− 2.4	88	28	68	31	8	52	24	53	49	75	0.82	− 2.7	7	10,601	ne.	49	sw.	19	17	8	6	3.9	T.	0.0	
Florida Peninsula.							**67.5**	**− 5.1**														**76**	**0.41**	**− 1.9**									**3.8**		
Key West	22	10	64	30.05	30.07	+ .02	70.8	− 2.0	84	27	76	49	2	66	19	65	62	78	0.58	0.9	4	9,214	e.	44	nw.	1	23	6	2	2.6	0.0	0.0	
Miami	25	71	79	30.07	30.10	.....	67.6	− 4.4	83	29	75	34	2	61	32	62	58	75	0.08	− 2.7	3	7,071	e.	32	nw	1	16	9	6	4.2	0.0	0.0	
Sand Key	23	39	72	30.02	30.05	.00	69.2	.....	79	27	72	52	2	66	12	65	63	81	.....	.....	.....	12,479	se.	50	nw.	1	21	6	4	3.2	0.0	0.0	
Tampa	35	79	92	30.07	30.11	+ .03	64.0	− 8.8	85	28	73	36	1	55	29	56	52	72	0.60	− 2.2	4	5,804	sw.	33	sw.	5	10	15	6	5.2	0.0	0.0	
East Gulf States.							**54.8**	**− 2.5**														**70**	**6.04**	**0.0**									**5.3**		
Atlanta	1,174	190	216	28.84	30.10	+ .04	49.6	− 2.8	77	27	58	16	8	41	28	43	37	65	10.9	+ 5.2	9	10,546	nw.	52	n.	5	13	5	13	5.4	0.0	0.0	
Leesburg	279	10	55	29.82	30.14	.....	55.2	.....	85	28	65	24	8	45	32	48	43	70	7.07	.....	9	6,981	s.	35	nw.	13	12	5	14	5.5	0.0	0.0	
Macon	370	78	87	29.70	30.11	+ .05	53.2	− 1.6	81	27	63	17	8	43	35	46	40	65	7.91	+ 2.4	11	5,759	nw.	59	nw.	28	15	4	12	4.7	0.0	0.0	
Thomasville	273	49	58	29.81	30.11	+ .05	57.4	− 2.8	84	27	67	26	1	48	29	49	43	67	3.21	− 1.9	7	4,443	sw.	24	sw.	19	11	7	13	5.5	0.0	0.0	
Pensacola	56	149	185	30.03	30.09	+ .03	56.8	− 4.8	74	26	63	24	1	50	35	52	48	76	1.31	− 4.0	8	11,977	se.	48	s.	4	9	7	15	6.3	T.	0.0	
Anniston	741	9	57	29.31	30.11	+ .05	49.8	− 2.7	80	27	61	13	8	39	39	.....	.....	.....	7.13	+ 1.4	10	6,253	se.	28	se.	25	14	6	11	4.9	T.	0.0	
Birmingham	700	11	48	29.33	30.11	+ .05	52.1	− 3.1	80	27	62	17	1	42	32	44	37	62	10.34	+ 4.6	11	7,539	s.	38	se.	11	13	5	13	5.1	T.	0.0	
Mobile	57	125	161	30.02	30.08	+ .02	57.8	− 1.3	81	26	66	25	1	50	35	52	48	75	2.21	− 5.0	7	9,697	se.	45	nw.	4	8	8	15	5.8	T.	0.0	
Montgomery	223	100	112	29.85	30.11	+ .05	54.2	− 3.7	81	27	64	22	1	45	32	48	41	64	7.88	+ 1.5	11	6,621	se.	31	se.	4	15	4	12	4.9	0.0	0.0	
Corinth	469	6	....	.....	.....	.....	51.8	.....	84	28	63	17	1	41	39	.....	.....	.....	4.06	.....	11	.....	s.	.....	.....	.....	7	16	8	....	0.0	0.0	
Meridian	375	85	93	29.67	30.08	+ .03	54.3	− 2.0	82	27	64	23	1	44	36	48	42	69	7.19	+ 1.6	13	5,760	s.	31	se.	25	12	4	15	5.5	0.0	0.0	
Vicksburg	247	65	74	29.77	30.06	+ .02	56.9	− 1.3	82	27	66	26	5	48	26	49	43	68	5.05	− 1.2	10	7,436	se.	40	se.	25	10	8	13	5.7	T.	0.0	
New Orleans	53	76	84	30.01	30.07	+ .03	60.3	− 1.7	84	26	68	31	1	53	26	57	55	88	3.28	− 2.0	11	6,183	sw.	26	nw.	12	8	5	18	6.6	T.	0.0	
West Gulf States.							**56.9**	**− 0.9**														**66**	**2.58**	**0.0**									**5.4**		
Shreveport	249	77	93	29.75	30.02	.00	56.9	− 1.3	82	27	66	24	7	48	30	48	41	62	5.08	+ 0.6	9	7,772	se.	39	w.	25	16	3	12	5.0	T.	0.0	
Bentonville	1,303	11	44	28.57	29.96	− .05	47.2	− 0.1	76	27	58	4	7	37	32	.....	.....	.....	6.60	+ 2.6	12	7,009	s.	35	s.	15	10	10	11	5.4	1.8	0.0	
Fort Smith	457	79	94	29.47	29.96	− .05	52.0	+ 0.7	81	27	62	13	7	42	32	44	37	62	3.90	+ 0.3	10	7,874	e.	48	sw.	27	11	9	11	5.2	0.3	0.0	
Little Rock	357	139	147	29.61	30.00	− .03	53.0	+ 0.3	80	27	62	17	7	44	30	46	40	68	4.80	− 0.1	9	8,823	s.	40	nw.	19	15	4	12	4.8	0.0	0.0	
Brownsville	57	4	26	.....	.....	.....	66.4	.....	90	25	76	32	8	56	39	.....	.....	.....	0.76	.....	2	.....	se.	.....	.....	.....	.....	.....	.....	.....	0.0	0.0	
Corpus Christi	20	60	77	29.97	29.99	+ .01	62.6	− 1.8	81	25	69	36	8	56	25	56	52	76	0.18	− 1.7	3	11,193	se.	52	se.	24	11	4	16	5.9	0.0	0.0	
Dallas	512	109	117	29.44	29.99	.....	56.6	.....	82	18	67	20	7	46	42	.....	.....	.....	5.62	.....	6	9,644	s.	58	sw.	25	14	6	11	4.7	T.	0.0	
Fort Worth	670	106	114	29.22	29.93	− .05	56.4	− 0.2	84	3	68	20	7	45	48	47	38	56	4.42	+ 2.7	5	10,350	s.	58	w.	25	14	7	10	4.7	0.0	0.0	
Galveston	54	106	114	29.97	30.03	+ .02	60.0	− 2.3	77	25	65	35	5	55	23	56	52	80	1.77	− 1.1	7	10,286	se.	43	nw.	25	10	3	18	6.4	0.0	0.0	
Groesbeck	461	11	56	29.48	29.96	.....	57.8	.....	83	16	69	23	7	47	38	50	43	65	1.44	.....	6	11,184	s.	60	nw.	25	14	8	9	4.8	T.	0.0	
Houston	138	111	121	.....	30.02	.....	61.6	− 1.9	84	26	70	31	1	53	28	.....	.....	.....	2.31	.....	12	8,310	se.	37	s.	24	10	3	18	6.2	T.	0.0	
Palestine	510	64	72	29.47	30.00	00	57.8	− 0.7	81	26	68	23	7	48	31	49	42	63	1.95	− 1.5	9	8,053	s.	39	sw.	25	12	6	13	5.6	0.1	0.0	
Port Arthur	34	58	66	29.97	30.01	.....	59.0	.....	79	26	65	31	1	53	22	54	50	78	2.57	.....	9	9,389	s.	47	nw.	25	9	6	16	6.5	0.0	0.0	
San Antonio	701	119	132	29.25	29.98	.00	60.4	− 1.7	85	26	72	29	7	49	37	51	42	59	0.83	− 0.8	6	6,972	se.	50	nw.	24	12	5	14	5.5	0.0	0.0	
Taylor	582	55	63	29.41	30.02	+ .03	58.4	− 1.3	84	17	70	24	7	47	37	.....	.....	.....	1.30	− 1.3	10	8,695	s.	47	nw.	24	14	4	13	5.3	0.0	0.0	

TABLE I.—*Climatological data for Weather Bureau Stations, March, 1920*—Continued.

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.										Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation.			Wind.						Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.					Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	° *F.*	° *F.*	° *F*		° *F*	° *F*		° *F*	° *F*		° *F*	° *F*	%	*In*	*In.*		*Miles*								*0–10*	*In.*	*In.*
Ohio Valley and Tennessee.							**45.3**	**+ 1.4**											**66**	**4.21**	**− 0.2**										**5.2**		
Chattanooga	762	189	213	29.29	30.12	+ .06	48.5	− 2.8	77	27	58	15	8	39	33		41	33	61	7.65	+ 1.4	12	8,089	s.	43	se.	25	11	7	13	5.3	0.2	0.0
Knoxville	996	102	111	29.01	30.08	+ .02	48.0	− 0.2	78	27	58	14	8	38	31		41	34	64	4.89	− 0.7	11	4,755	sw.	36	sw.	19	10	10	11	5.1	0.5	0.0
Memphis	399	70	97	29.63	30.06	+ .02	51.8	− 0.3	79	27	60	17	7	44	28		45	38	62	4.72	− 1.0	9	9,285	se.	42	sw.	25	15	5	11	4.8	T.	0.0
Nashville	546	168	191	29.48	30.08	+ .03	48.5	− 0.7	80	28	58	14	7	39	34		41	34	63	3.25	− 2.2	11	10,433	s.	48	se.	25	11	12	8	4.9	0.4	0.0
Lexington	989	193	230	28.98	30.06	+ .01	44.9	+ 1.5	75	27	54	9	7	36	33		....	....	....	4.62	− 0.1	12	13,853	sw.	56	sw.	15	14	4	13	5.1	1.0	0.0
Louisville	525	219	255	29.45	30.04	− .01	46.6	+ 1.3	78	27	56	10	7	37	29		40	33	64	5.49	+ 1.2	10	12,567	s.	56	s.	11	14	9	8	4.2	T.	0.0
Evansville	431	139	175	29.55	30.02	− .02	46.6	+ 2.0	79	27	56	11	7	38	30		41	34	71	6.10	+ 1.5	12	12,259	sw.	57	sw.	25	9	11	11	5.5	0.9	0.0
Indianapolis	822	194	230	29.08	29.98	− .06	42.3	+ 2.7	75	28	51	6	7	33	28		37	31	68	2.66	− 1.4	11	12,956	s.	56	s.	28	12	6	13	5.5	0.3	0.0
Royal Center	736	11	55	29.13	29.95	.....	39.9	.....	75	28	49	4	7	31	12		35	29	69	2.87	.....	12	11,932	s.	48	w.	15	10	9	12	5.9	0.2	0.0
Terra Haute	575	90	129	29.33	29.96	.....	43.6	.....	77	28	53	6	7	34	34		38	34	72	3.90	.....	11	11,214	s.	54	sw.	28	8	14	9	5.8	0.9	0.0
Cincinnati	628	11	51	29.33	30.02	− .03	44.0	+ 3.2	72	25	54	11	7	34	32		38	32	66	4.20	+ 0.6	10	9,000	sw.	58	sw.	29	14	7	10	4.7	0.4	0.0
Columbus	824	179	222	29.12	30.01	− .03	42.8	+ 3.6	74	25	53	10	6	32	33		37	32	71	3.32	+ 0.1	13	12,048	sw.	58	w.	29	11	9	11	5.6	1.8	0.0
Dayton	893	181	216	29.00	29.97	.....	42.6	+ 2.3	71	31	52	9	7	33	31		36	30	63	2.78	− 0.7	12	12,007	sw.	60	s.	28	12	9	10	4.8	0.3	0.0
Elkins	1,947	59	67	27.98	30.07	+ .02	40.3	+ 1.2	72	26	52	7	8	28	43		34	28	71	4.57	+ 0.5	12	5,928	w.	31	se.	4	11	9	11	5.2	9.1	0.0
Parkersburg	638	77	84	29.39	30.06	+ .01	45.2	+ 2.9	76	28	56	14	6	34	36		37	29	60	2.92	− 0.9	11	6,546	se.	46	w.	12	13	11	7	4.6	0.9	0.0
Pittsburgh	842	353	410	29.10	30.02	− .02	42.6	+ 3.1	73	28	52	9	6	33	36		36	28	61	1.77	− 1.2	10	11,529	sw.	70	w.	12	10	8	13	5.5	3.1	0.0
Lower Lake Region.							**37.2**	**+ 4.3**											**70**	**1.94**	**− 0.7**										**5.6**		
Buffalo	767	247	280	29.10	29.95	− .07	36.0	+ 4.8	76	25	45	**4**	6	27	43		3	27	74	1.57	− 1.0	14	16,223	sw.	64	w.	26	7	9	15	6.3	6.3	0.0
Canton	448	10	61	29.42	29.91	.....	30.7	+ 3.0	71	25	40	**−20**	2	22	41		..	..	....	2.26	− 0.6	16	11,251	sw.	48	sw.	8	13	4	14	5.2	11.1	T.
Oswego	335	76	91	29.56	29.94	− .04	33.4	+ 2.0	66	28	42	− 2	2	25	21		30	26	77	2.44	− 0.4	15	9,931	s.	34	nw.	17	7	10	14	6.0	16.5	0.0
Rochester	523	86	102	29.37	29.94	− .06	36.1	+ 4.8	74	26	45	7	7	27	32		31	24	66	2.16	− 0.8	17	8,810	w.	44	w.	29	8	9	14	6.0	16.3	0.0
Syracuse	597	97	113	29.31	29.97	− .05	36.2	+ 4.8	70	28	45	3	2	27	34		....	....	....	2.72	+ 0.3	15	11,591	s.	46	w.	30	10	9	12	5.9	12.6	0.0
Erie	714	139	166	29.17	29.96	− .06	38.4	+ 5.3	75	25	48	9	7	29	40		33	26	67	1.33	− 1.3	11	14,025	w.	58	se.	4	9	14	8	4.9	2.7	0.0
Cleveland	762	190	201	29.14	29.98	− .05	40.0	+ 5.8	74	25	49	9	6	31	30		34	29	68	1.49	− 1.3	15	13,474	sw.	48	s.	28	8	12	11	5.9	2.7	0.0
Sandusky	629	62	103	29.27	29.97	− .06	40.8	+ 5.8	75	25	50	8	6	31	34		....	....	....	1.38	− 1.2	12	13,026	sw.	54	sw.	28	5	17	9	5.6	2.9	0.0
Toledo	628	208	243	29.26	29.95	− .08	39.5	+ 4.7	73	31	49	9	6	30	32		34	28	67	1.97	− 0.3	13	14,663	sw.	66	se.	28	13	10	8	4.6	2.4	0.0
Fort Wayne	850	113	124	29.02	29.90	.....	40.2	+ 1.3	73	31	49	7	7	31	32		35	28	66	2.55	.....	12	10,448	sw.	44	s.	26	10	9	12	5.5	0.6	0.0
Detroit	730	218	245	29.14	29.95	− .08	37.7	+ 4.8	70	31	47	6	6	28	29		32	27	73	2.09	− 0.3	12	11,457	sw.	54	sw.	12	9	10	12	5.9	1.1	0.0
Upper Lake Region.							**31.0**	**+ 3.5**											**78**	**3.14**	**+ 1.0**										**5.7**		
Alpena	609	13	92	29.20	29.89	− .14	27.7	+ 2.7	65	23	37	− 6	7	18	33		25	22	81	1.30	− 0.7	11	10,761	se.	46	se.	15	8	10	13	6.3	3.0	0.0
Escanaba	612	54	60	29.17	29.86	− .18	26.2	+ 2.7	47	30	34	− 9	7	18	30		23	20	84	2.87	**+ 0.9**	13	7,860	s.	38	sw.	16	15	6	10	4.2	9.4	0.0
Grand Haven	632	54	89	29.19	29.89	− .14	34.0	+ 3.2	65	28	42	4	6	26	27		31	27	78	4.00	+ 1.5	15	11,573	s.	53	se.	28	7	11	13	6.3	7.5	0.0
Grand Rapids	707	70	87	29.12	29.91	− .12	36.1	+ 3.1	72	31	45	0	6	27	32		31	24	71	3.42	+ 0.9	11	5,921	s.	33	s.	8	8	9	14	6.7	3.4	0.0
Houghton	684	62	99	29.09	29.84	− .20	25.0	+ 1.2	64	22	35	− 6	3	15	47		....	....	....	2.10	+ 1.1	14	8,210	e.	40	w.	29	9	7	15	5.7	19.9	T.
Lansing	878	11	62	28.95	29.91	.....	35.2	+ 3.9	72	31	46	0	6	25	32		31	27	77	3.57	+ 1.3	13	7,258	s.	35	se.	28	7	11	13	6.2	3.7	0.0
Ludington	637	60	66	29.16	29.88	.....	32.5	.....	65	28	40	1	6	25	26		30	27	83	5.21	.....	12	10,661	s.	48	se.	28	8	11	12	6.1	7.9	0.0
Marquette	734	77	111	29.05	29.87	− .17	28.0	+ 4.3	60	23	36	− 3	6	20	31		24	21	80	3.34	+ 1.3	16	9,146	nw.	42	sw.	10	10	7	14	5.9	19.3	T.
Port Huron	638	70	120	29.22	29.93	− .10	35.2	+ 5.6	68	31	45	3	6	26	32		30	27	78	1.53	− 0.9	10	11,335	sw.	50	w.	16	6	14	11	5.7	2.6	0.0
Saginaw	641	69	77	29.20	29.91	.....	34.2	.....	71	31	43	2	6	25	29		30	26	74	2.68	0.0	10	8,609	sw.	43	sw.	10	11	8	12	5.6	7.5	0.0
Sault Sainte Marie	614	11	52	29.16	29.88	− .15	24.0	+ 2.7	56	23	34	−14	7	14	37		21	18	81	3.62	+ 1.8	12	7,367	se.	38	nw.	29	11	5	15	5.9	12.0	T.
Chicago	823	140	310	29.01	29.91	− .12	40.2	+ 5.8	73	31	48	3	7	32	26		35	30	69	4.57	+ 2.0	12	12,414	s.	49	s.	15	14	6	11	4.8	3.3	0.0
Green Bay	617	109	144	29.17	29.85	− .19	31.1	+ 4.3	67	31	40	−11	7	22	28		27	23	74	4.12	+ 1.7	12	10,672	s.	62	sw.	16	9	10	12	6.3	13.9	0.0
Milwaukee	681	125	139	29.12	29.87	− .16	35.6	+ 4.7	72	31	44	− 2	7	27	27		32	28	77	4.53	+ 1.9	11	9,663	sw.	44	sw.	16	10	9	12	5.5	4.6	0.0
Duluth	1,133	11	47	28.58	29.83	− .23	25.3	+ 1.2	57	22	33	−13	6	17	30		22	19	83	2.28	+ 0.7	11	11,873	ne.	57	nw.	28	15	4	12	4.8	7.0	0.0
North Dakota.							**23.5**	**+ 2.6**											**82**	**1.02**	**0.0**										**4.9**		
Moorhead	940	8	57	28.82	29.87	− .21	25.3	+ 3.9	69	31	35	−16	5	16	35		22	19	84	0.32	− 0.8	5	7,932	n.	40	nw.	16	17	6	8	4.0	2.3	0.0
Bismarck	1,674	8	57	28.05	29.89	− .19	26.0	+ 3.9	64	30	38	−17	7	14	44		22	18	79	1.21	+ 0.2	5	8,095	nw.	56	nw.	15	13	10	8	5.0	11.7	0.0
Devils Lake	1,482	11	44	28.21	29.85	− .20	19.1	+ 0.6	55	22	29	**−23**	5	9	**38**	**17**	**15**	**89**	**0.35**	**− 0.7**	3	8,812	nw.	60	n.	15	10	11	10	5.2	3.6	0.0
Ellendale	1,457	10	56	28.24	29.84	.....	26.2	.....	66	30	37	−19	7	15	39		23	19	79	0.42	.....	5	12,621	nw.	65	nw.	15	11	11	9	5.3	4.8	0.0
Grand Forks	835	12	89	.....	.....	.....	20.6	.....	56	31	31	−22	5	11	39		18	....	....	0.61	.....	4	.....	nw.	70	n.	16	18	8	5	....	11.7	T.
Williston	1,878	41	48	27.81	29.85	− .19	23.7	+ 2.1	58	30	34	−16	4	14	36		21	17	77	2.18	+ 1.5	10	6,676	w.	48	nw.	15	10	14	7	5.1	9.8	T.
Upper Mississippi Valley.							**39.7**	**+ 3.7**											**72**	**3.96**	**− 1.5**										**5.0**		
Minneapolis	918	102	208	28.80	29.80	.....	31.2	.....	73	31	41	− 9	6	22	32		....	....	....	2.71	+ 1.1	8	11,075	nw.	56	sw.	15	12	8	11	5.3	14.3	0.0
St. Paul	837	236	261	28.90	29.83	− .22	30.6	+ 2.4	71	31	40	−12	7	21	31		....	....	....	2.91	+ 1.3	9	11,873	se.	60	sw.	15	13	8	10	4.5	18.5	0.0
La Crosse	714	11	48	29.05	29.84	− .20	34.1	+ 3.2	74	31	44	− 9	7	24	35		....	....	....	2.89	+ 1.2	12	5,743	s.	38	sw.	16	10	10	11	5.4	9.9	0.0
Madison	974	70	78	28.80	29.88	− .16	34.0	+ 3.9	72	31	43	− 7	7	25	29	30	26	79	4.07	+ 1.9	12	9,744	se.	50	s.	15	10	9	12	5.5	3.8	0.0
Wausau	1,247	4	....	28.45	29.82	.....	29.2	.....	69	31	39	−17	6	20	31		....	....	....	2.42	.....	10	.....	se.	....	.....	.....	10	8	13	....	10.4	0.0
Charles City	1,015	10	49	28.75	29.85	− .25	34.4	+ 6.0	75	31	44	− 8	7	24	34	30	27	81	2.85	+ 0.9	10	7,946	nw.	42	nw.	16	9	12	10	5.4	6.4	0.0
Davenport	606	71	79	29.21	29.89	− .25	40.3	+ 4.9	75	31	50	0	7	30	35	35	30	75	4.45	+ 2.2	11	7,939	sw.	40	sw.	28	16	3	12	4.8	1.4	0.0
Des Moines	861	84	97	28.92	29.84	− .20	39.8	+ 4.1	76	31	50	0	7	30	32	35	30	72	3.92	+ 2.3	10	7,869	sw.	38	sw.	15	13	4	14	5.1	0.2	0.0
Dubuque	698	81	96	29.12	29.89	− .20	37.2	+ 4.0	75	31	47	− 3	7	28	31	33	28	75	3.04	+ 0.8	11	6,877	nw.	32	s.	15	13	8	10	5.2	5.6	0.0
Keokuk	614	64	78	29.22	29.91	− .12	42.6	+ 4.7	78	27	53	0	7	33	34	36	29	64	4.02	+ 1.6	10	8,921	s.	52	sw.	28	11	10	10	5.1	3.3	0.0
Cairo	356	87	93	29.62	30.01	− .11	47.9	+ 0.9	77	27	56	13	7	39	27	41	35	65	3.94	− 0.1	11	9,869	s.	49	sw.	28	12	7	12	5.5	0.2	0.0
Peoria	609	11	45	29.25	29.92	− .18	41.5	+ 4.5	75	31	52	1	7	31	38	36	31	75	5.84	+ 2.9	11	8,388	s.	44	sw.	28	17	4	10	4.5	0.3	0.0
Springfield, Ill.	644	10	91	29.24	29.92	− .18	43.0	+ 3.9	76	27	53	4	7	33	34	37	32	72	6.34	+ 3.3	12	9,720	s.	41	sw.	28	13	8	10	4.7	0.3	0.0
Hannibal	534	74	109	29.33	29.91	− .20	43.8	+ 2.2	80	27	54	1	7	34	34	....	....	....	....	4.47	+ 1.7	12	10,749	sw.	58	sw.	28	12	8	11	5.1	1.3	0.0
St. Louis	567	265	303	29.33	29.95	− .08	46.6	+ 3.1	80	27	56	7	7	37	31	39	31	62	3.97	+ 0.5	9	15,045	sw.	74	sw.	25	15	6	10	4.4	1.9	0.0
Missouri Valley.							**39.6**	**+ 4.0**											**68**	**2.78**	**+0.8**										**4.6**		
Columbia, Mo.	781	11	84	29.07	29.92	− .11	45.6	+ 4.2	79	27	56	− 1	7	35	37	....	....	....	....	5.03	+2.0	10	9,667	se.	64	s.	25	13	8	10	4.9	2.1	0.0
Kansas City	963	161	181	28.84	29.89	− .13	45.3	+ 4.5	75	27	56	3	7	35	32	38	30	60	4.32	+1.5	10	13,217	s.	55	w.	18	14	10	7	4.2	2.0	0.0
St. Joseph	967	11	49	28.82	29.87	.....	44.2	.....	77	31	55	1	7	33	35	37	29	61	5.05	.....	9	10,336	se.	52	w.	19	14	9	8	4.4	0.2	0.0
Springfield, Mo.	1,324	98	104	28.53	29.95	− .07	45.6	+ 2.1	76	27	55	1	7	36	30	38	31	66	4.90	+ 0.8	12	11,716	se.	51	sw.	28	16	8	7	4.0	4.1	0.0
Iola	984	11	50	28.85	29.91	− .10	46.4	+ 4.0	74	30	59	1	7	34	44	....	....	....	....	5.36	+ 3.0	10	8,549	s.	36	w.	18	10	11	10	5.5	1.1	0.0
Topeka	987	92	107	.....	.....	.....	45.6	.....	77	31	58	2	7	34	40	....	....	....	....	3.28	+ 1.0	6	12,301	sw.	50	w.	18	13	10	8	4.2	0.8	0.0
Drexel	1,299	10	53	28.42	29.83	.....	39.4	.....	79	31	51	− 4	7	28	35	33	28	72	2.10	.....	7	11,682	nw	54	s.	22	15	8	8	4.8	1.6	0.0
Lincoln	1,189	11	84	28.56	29.84	− .18	42.6	+ 6.6	79	31	55	− 1	7	30	39	34	26	60	0.68	− 0.6	7	11,412	se.	58	n.	28	14	7	10	4.5	0.8	0.0
Omaha	1,105	115	122	28.65	29.85	− .19	41.6	+ 5.6	79	31	53	− 1	7	31	32	34	27	63	0.47	− 0.9	6	8,771	nw.	58	nw.	28	12	12	7	4.6	0.5	0.0
Valentine	2,598	47	54	27.09	29.86	− .17	34.6	+ 2.7	72	22	48	−15	7	22	48	28	21	68	1.04	− 0.2	9	9,720	nw.	50	w.	15	12	12	7	4.5	10.2	0.0
Sioux City	1,135	94	164	28.61	29.84	− .20	36.8	+ 4.2	76	27	47	− 9	5	26	32	32	27	74	2.38	+ 1.1	6	12,300	nw.	65	w.	16	14	9	8	4.7	8.2	0.0
Huron	1,306	59	74	28.44	29.87	− .19	29.9	+ 3.2	68	30	40	−14	7	20	38	26	22	78	1.72	+ 0.7	10	10,181	nw.	60	nw.	15	16	6	9	4.4	13.6	0.0
Pierre	1,572	70	75	28.16	29.87	− .18	32.0	+ 3.5	71	22	43	−15	7	21	45	28	25	80	1.78	+ 0.4	7	8,262	nw.	64	w.	15	14	8	9	4.5	17.8	0.0
Yankton	1,233	49	57	28.50	29.84	− .21	34.9	+ 3.7	75	31	46	−11	7	24	36	....	....	....	....	2.44	+ 1.3	8	8,421	w.	44	s.	22	14	9	8	5.1	10.9	0.0

TABLE I.—*Climatological data for Weather Bureau Stations, March, 1920*—Continued.

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.												Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation.			Wind.						Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.						Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	°F.	°F.	°F		°F	°F		°F	°F	°F	°F	%	*In.*	*In.*		*Miles*								0–10	*In.*	*In.*
Northern Slope.							**30.1**	**− 0.8**										**66**	**0.91**	**− 0.2**										**5.2**		
Billings	3,140	5					31.0		65	21	42	−34	6	20	42				0.95			6		sw.				9	12	10		12.5	4.0
Havre	2,505	11	44	27.17	29.89	− .14	27.6	+ 0.3	64	21	38	−26	6	17	48	25	21	78	0.46	0.0	7	7,048	sw.	38	sw.	30	13	10	8	4.4	3.2	0.7
Helena	4,110	87	112	25.61	29.90	− .11	28.9	− 2.1	58	21	38	−20	6	20	29	24	15	59	1.27	+ 0.5	11	5,914	sw.	37	sw.	14	7	7	17	6.3	12.5	T.
Kalispell	2,973	48	50		29.85	− .14	31.2	− 1.8	57	21	39	− 8	6	23	32				0.92	− 0.2	12	4,218	nw.	36	ne.	5	7	6	18	4.0	3.5	0.0
Miles City	2,371	9	48	27.31	29.92	− .10	29.8	+ 1.2	65	30	39	−20	7	20	52	26	23	81	1.31	+ 0.6	13	5,091	sw.	44	nw.	15	5	19	7	5.7	9.3	T.
Rapid City	3,259	50	58	26.40	29.89	− .12	32.1	+ 0.5	70	21	44	−14	7	20	47	27	19	60	0.57	− 0.5	6	7,949	nw.	46	w	15	7	14	10	5.6	4.6	0.0
Cheyenne	6,088	80	101	23.78	29.85	− .11	31.5	− 1.5	61	14	42	−14	6	20	40	25	16	56	0.66	− 0.3	7	12,864	w.	74	w.	18	8	13	10	5.7	6.5	0.2
Lander	5,372	60	68	24.44	29.91	− .08	28.0	− 3.3	59	21	40	−19	6	16	39	23	16	64	0.64	− 1.0	9	3,899	w.	40	sw.	14	13	13	5	4.6	3.5	0.0
Sheridan	3,799	10	47	25.91	29.89		30.4		64	30	42	−17	6	19	50	25	18	68	0.83		11	5,307	nw.	42	nw.	15	10	11	10	4.9	10.1	T.
Yellowstone Park	6,200	11	48	23.60	29.91	− .11	23.5	− 3.0	52	21	34	−25	6	13	38	21	16	73	1.95	− 0.2	17	6,366	s.	30	s.	11	5	11	15	7.1	20.0	18.8
North Platte	2,821	11	51	26.91	29.88	− .12	37.9	+ 2.6	76	22	52	−13	7	24	48	29	21	59	0.38	− 0.5	5	7,407	nw.	52	n.	28	19	5	7	3.7	2.6	0.0
Middle Slope.							**44.2**	**+ 1.7**										**53**	**1.17**	**+ 0.3**										**4.3**		
Denver	5,292	10	113	24.53	29.82	− .13	37.8	− 0.9	70	21	50	− 4	6	26	41	30	19	51	0.62	− 0.4	7	69,76	s.	51	w.	18	12	13	6	4.8	7.3	0.0
Pueblo	4,685	80	80	25.09	29.80	− .12	40.5	− 0.1	73	21	56	−10	7	26	50	30	14	40	0.15	− 0.7	4	7,051	w.	58	w.	14	15	8	8	4.4	0.8	0.0
Concordia	1,392	50	58	28.38	29.87	− .14	44.8	+ 4.1	79	14	58	− 1	7	31	44	35	25	57	0.47	− 1.0	5	9,709	s.	46	nw.	28	13	13	5	4.7	0.7	0.0
Dodge City	2,570	11	51	27.29	29.88	− .09	45.0	+ 3.3	79	14	61	−10	7	29	51	33	19	47	0.43	− 0.4	4	10,870	nw.	50	nw.	28	21	7	3	2.6	0.3	0.0
Wichita	1,358	139	158	28.44	29.89	− .10	47.1	+ 3.0	79	14	60	1	7	35	49	38	28	54	1.13	− 1.1	2	14,994	s.	60	s.	14	18	7	6	3.8	T	0.0
Altus	1,410	5					52.4		83	14	66	10	7	35	47				1.85		5		se.				17	3	11		0.0	0.0
Broken Arrow	765	11	52	29.11	29.95		48.9		70	30	60	8	7	38	50	42	36	69	4.34		7	13,720	s.	57	nw.	3	10	14	7	5.0	T	0.0
Muskogee	652	4					50.7		78	30	62	10	7	39	40				5.77		9		se.				11	12	8		0.4	0.0
Oklahoma	1,214	10	47	28.63	29.93	− .05	50.1	+ 0.9	78	31	62	7	7	38	49	41	32	56	4.20	+ 1.8	9	14,006	s.	53	w.	28	14	8	9	4.9	0.2	0.0
Southern Slope.							**53.0**	**− 0.2**										**47**	**0.20**	**− 0.7**										**3.8**		
Abilene	1,738	10	52	28.11	29.92	− .04	56.0	+ 1.1	86	27	70	16	6	42	42	43	29	43	0.01	− 1.4	1	10,779	s.	48	w.	3	16	7	8	4.3	0.0	0.0
Amarillo	3,676	10	49	26.13	29.88	− .07	47.2	+ 2.2	80	14	63	6	6	32	50	37	27	57	0.51	− 0.1	5	10,760	sw.	49	sw.	27	16	13	2	3.7	0.7	0.0
Del Rio	944	64	71	28.98	29.97	+ .02	59.8	− 1.9	92	27	72	30	1	47	42				0.15	− 1.0	3	8,499	se.	49	nw.	24	13	9	9	4.6	0.0	0.0
Roswell	3,566	75	85	26.25	29.86	− .04	49.2	− 2.1	79	14	66	14	8	32	51	37	22	41	0.12	− 0.3	2	8,985	s.	48	w.	27	19	11	1	2.5	T	0.0
Southern Plateau.							**48.6**	**− 2.3**										**47**	**0.64**	**+ 0.1**										**3.0**		
El Paso	3,762	110	133	26.11	29.87	− .01	53.6	− 2.3	79	14	67	24	7	40	41	40	21	34	0.22	− 0.2	2	11,233	w.	55	sw.	27	16	11	4	3.6	0.0	0.0
Santa Fe	7,013	57	66	23.08	29.84	− .05	37.4	− 2.0	61	21	48	5	7	26	37	29	20	55	0.57	− 0.2	4	7,524	sw.	42	sw.	14	14	8	9	4.3	3.4	0.0
Flagstaff	6,908	8	57	23.21	29.84	− .07	34.2	− 1.7	62	13	46	3	18	22	45	29			3.11		12	7,743	sw.	46	sw.	14	16	9	6		13.5	1.0
Phoenix	1,108	76	81	28.75	29.91	00	58.4	− 2.1	83	20	72	36	28	45	39	47	37	54	1.35	+ 0.9	6	4,293	e.	24	w.	26	19	9	3	2.9	00	0.0
Yuma	141	9	54	29.78	29.93	− .01	61.4	− 3.1	84	20	75	41	28	48	37	50	39	51	0.37	0.0	4	4,239	w.	28	w.	26	27	3	1	1.1	00	0.0
Independence	3,957	9	41	25.87	29.91	− .03	46.8	− 2.8	72	13	60	25	27	34	34	36	22	41	0.67	+ 0.2	5	5,193	nw.	38	nw.	14	17	10	4	3.3	0.2	0.0
Middle Plateau.							**38.3**	**− 2.7**										**59**	**1.70**	**+ 0.2**										**5.5**		
Reno	4,532	74	81	25.36	29.94	− .04	39.4	− 1.6	65	12	51	19	18	27	39	33	25	60	0.57	− 0.6	9	6,096	w.	37	w.	14	13	11	7	4.6	4.7	0.0
Tonopah	6,090	12	20	23.93	29.90	− .08	37.2	− 3.8	62	13	47	15	27	28	32	30	21	55	0.84	− 0.5	8	9,125	nw.	52	nw.	14	13	16	2	3.9	10.0	0.0
Winnemucca	4,344	18	56	25.51	29.93	− .08	38.5	− 1.1	65	20	49	22	27	28	37	32	26	64	1.73	− 0.8	10	6,263	sw.	43	sw.	13	7	10	14	6.3	6.5	0.0
Modena	5,479	10	43	24.48	29.88	− .08	35.3	− 3.9	63	13	48	11	27	23	41	29	20	58	1.84	+ 0.5	9	9,172	sw.	56	sw.	14	10	12	9	4.9	6.8	T.
Salt Lake City	4,360	163	203	25.50	29.90	− .08	39.2	− 2.2	68	21	48	21	31	31	35	33	26	63	3.81	+ 1.8	15	5,959	nw.	60	w.	2	4	6	21	7.5	32.0	0.5
Grand Junction	4,602	60	68	25.26	29.85	− .09	40.0	− 3.5	68	21	50	19	28	30	34	32	22	53	1.39	+ 0.7	12	5,742	se.	50	sw.	14	8	14	9	5.7	5.1	3.5
Northern Plateau.							**40.4**	**+ 0.6**										**64**	**1.53**	**0.0**										**6.8**		
Baker	3,471	48	53	26.30	29.91	− .12	36.8	+ 3.5	55	20	44	21	15	29	29	33	27	70	1.66	+ 0.2	14	4,742	se.	28	s.	13	8	9	14	6.1	4.7	0.0
Boise	2,739	78	86	27.05	29.93	− .10	40.8	− 1.4	65	20	50	24	31	32	31	37	30	65	1.89	+ 0.4	12	4,950	nw.	30	w.	13	6	17	8	6.2	2.9	0.0
Lewiston	757	40	48	29.08	29.90	− .13	44.4	+ 0.4	68	20	53	27	1	36	34				1.25	0.0	14	3,466	e.	33	w.	30	3	6	22	7.8	T.	0.0
Pocatello	4,477	60	68	25.32	29.89	− .12	35.6	− 0.7	60	21	43	16	6	28	27	30	24	66	1.41	− 0.3	14	8,567	sw.	44	sw.	14	4	9	18	6.8	6.2	0.0
Spokane	1,929	101	110	27.81	29.88	− .13	39.4	+ 0.5	63	20	48	20	1	31	29	34	26	60	0.81	− 0.7	8	7,150	sw.	37	sw.	30	3	16	12	6.4	3.0	0.0
Walla Walla	991	57	65	28.83	29.91	− .11	45.2	+ 1.2	70	20	53	27	7	38	32	39	30	59	2.14	+ 0.2	14	5,702	s.	35	w.	30	3	9	19	7.5	2.5	0.0
North Pacific Coast Region.							**44.6**	**− 0.3**										**79**	**3.97**	**− 0.7**										**7.2**		
North Head	211	11	56	29.72	29.95	− .06	44.2	− 0.7	59	20	48	33	30	40	17	42	39	83	3.73	− 1.5	24	14,967	s.	72	nw.	30	5	15	11	6.5	T.	0.0
Port Angeles	29	8	53	29.88	29.92		41.8		56	21	49	27	1	34	22				1.54	− 0.6	18	4,894	s.	40	nw.	30	4	9	18	6.9	0.1	0.0
Seattle	125	215	250	29.80	29.93	− .06	44.4	+ 0.2	63	20	51	32	31	38	23	41	36	74	2.82	− 0.8	17	8,436	s.	43	s.	30	3	7	21	7.9	T.	0.0
Tacoma	213	113	120	29.70	29.93	− .07	44.4	+ 0.2	61	21	51	29	1	37	26	42	39	81	2.99	− 1.0	17	6,237	sw.	30	ne.	15	2	12	17	7.1	T.	0.0
Tatoosh Island	86	7	57	29.79	29.88	− .08	43.7	+ 0.8	52	20	47	34	31	40	10	42	40	86	9.78	+ 1.2	23	12,085	w.	59	w.	30	6	8	17	6.9	T.	0.0
Yakima	1,071	4																																
Medford	1,425	4					45.4		66	6	54	26	1	36	33				8.77		26		sw.				4	3	24		T.	0.0
Portland, Oreg.	153	68	106	29.81	29.97	− .05	45.8	− 0.5	62	22	53	32	1	39	24	42	38	75	3.94	− 1.2	20	5,418	sw.	28	sw.	3	3	4	24	8.2	1.5	0.0
Roseburg	510	9	57	29.47	30.03	− .01	44.8	− 1.8	66	12	53	29	1	36	31	41	37	77	2.97	− 1.0	19	2,424	s.	22	sw.	14	1	19	11	7.0	0.6	0.0
Middle Pacific Coast Region.							**49.0**	**− 2.3**										**76**	**3.98**	**− 0.2**										**4.6**		
Eureka	62	73	89	30.00	30.07	+ .01	47.0	− 1.0	66	19	53	33	26	41	23	44	42	82	5.79	− 1.2	17	6,154	se.	36	n.	30	4	13	14	6.3	0.0	0.0
Mount Tamalpais	2,375	11	18	27.52	30.01	− .05	43.4	− 3.7	61	29	49	30	26	37	22	40	37	81	4.23	− 0.9	13	14,612	nw.	88	nw.	13	18	4	9	4.5	0.1	0.0
Point Reyes Light	490	7	18	29.47	29.98		48.6	− 1.0	64	12	53	37	26	44	18				1.27		12	18,428	nw.	90	nw.	31	12	11	8	4.6	0.0	0.0
Red Bluff	332	50	56	29.64	30.00	− .04	49.8	− 4.0	76	6	60	28	26	39	36	44	38	68	3.89	+ 0.1	11	4,608	se.	36	nw.	30	13	6	12	5.1	0.0	0.0
Sacramento	69	106	117	29.95	30.02	− .01	51.0	− 3.2	71	29	60	34	26	42	27	47	42	73	3.27	+ 0.3	9	6,163	se.	40	nw.	31	17	7	7	3.7	0.0	0.0
San Francisco	155	208	243	29.86	30.03	− .03	52.6	− 0.1	69	6	59	41	26	46	22	46	43	74	3.25	+ 0.1	10	7,593	nw.	34	nw.	31	18	8	5	3.7	0.0	0.0
San Jose	141	12	110	29.90	30.05		50.9	− 2.9	70	20	61	34	3	41	33				3.43	+ 0.4	13	4,638	w.	30	nw.	14	15	8	8	4.3	0.0	0.0
South Pacific Coast Region.							**54.3**	**− 1.1**										**72**	**3.87**	**+ 1.2**										**4.0**		
Fresno	327	89	98	29.67	30.03	+ .02	52.7	− 2.2	75	20	62	36	27	43	29	67	41	69	3.98	+ 2.2	8	4,977	nw.	42	nw.	31	16	9	6	3.5	0.0	0.0
Los Angeles	338	159	191	29.64	30.01	− .01	56.8	− 0.1	80	13	65	43	18	48	29	50	44	69	4.25	+ 1.2	10	5,282	ne.	35	nw.	14	18	5	8	3.7	0.0	0.0
San Diego	87	62	70	29.92	30.01	− .01	55.6	− 0.6	77	12	62	41	18	49	27	51	47	76	2.46	+ 0.8	10	5,021	w.	34	s.	22	13	10	8	4.4	0.0	0.0
San Luis Obispo	201	32	40	29.83	30.05	− .01	52.2	− 1.6	76	12	62	33	17	42	31	46	41	72	4.78	+ 0.8	12	3,586	n.	22	ne.	5	16	7	8	4.2	0.0	0.0
West Indies.																																		
San Juan, P. R.	82	8	54	29.95	30.03	+ .01	75.8		88	2	81	68	19	70	15				3.48	+ 0.3	24	9,810	e.	40	e.	17	9	18	4	4.7	0.0	0.0
Panama Canal.																																		
Balboa Heights	118	7	97	29.74	29.86	.00	81.2	− 0.1	92	27	90	70	6	72	21	72	70	73	0.09	− 0.5	1	8,692	nw.	32	n.	8	7	24	0	4.5	0.0	0.0
Colon	36	7	97	29.85	29.88	− .01	81.8	+ 1.7	89	24	87	73	6	77	13	74	72	76	1.08	− 0.5	14	11,537	n.	30	n.	8	9	19	3	4.7	0.0	0.0
Alaska.																																		
Juneau	80	11	49				31.6		45	8	37	14	31	26	19	28	22	73	4.63		16	3,752	nw.	20	se.	5	9	7	15	6.4	28.3	4.8

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during March, 1920, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex.	25			0.01														0.01			
Albany, N. Y.	5			0.63														0.12			
Alpena, Mich.	4			0.32														(*)			
Amarillo, Tex.	24–25			0.42														(*)			
Anniston, Ala.	19	5:24 a. m.	9:45 a. m.	1.30	5:57 a. m.	6:23 a. m.	0.13	0.09	0.26	0.43	0.49	0.56	0.59								
Asheville, N. C.	19			0.64														0.43			
Atlanta, Ga.	12	5:10 a. m.	5:55 p. m.	3.45	12:22 p. m.	12:49 p. m.	1.63	0.09	0.43	0.93	1.10	1.19	(†)	(†)	(†)	(†)					
	16–17	4:35 p. m.	3:30 a. m.	1.46	2:43 a. m.	3:30 a. m.	0.45	0.14	0.20	0.26	0.47	0.70	0.85	0.91	0.97	1.01					
Atlantic City, N. J.	5			1.42			0.15			0.27	0.33	0.44	0.60	0.78	0.91			0.26			
Augusta, Ga.	12–13	5:20 p. m.	6:00 a. m.	2–11	7:02 p. m.	7:40 p. m.	0.02	0.16	0.20	0.79	1.07	1.11	1.12	1.13	1.21	1.54					
	28	4:10 p. m.	D.N. p. m.	1.88	6:15 p. m.	7:00 p. m.		0.12	0.34												
Baker, Oreg.	1–2			0.47														(*)			
Baltimore, Md.	5			1.11														0.22			
Bentonville, Ark.	11			1.92														0.72			
Binghamton, N. Y.	5			1.72														0.29			
Birmingham, Ala.	17	D.N. a. m.	12:17 p. m.	3.10	12:52 a. m.	1:42 a. m.	0.02	0.06	0.12	0.17	0.24	0.40	0.57	0.89	0.94	0.98	1.12				
					1:42 a. m.	2:32 a. m.		1.22	1.28	1.30	1.30	1.32	1.38	1.41	1.43	1.45	1.49				
					2:32 a. m.	3:05 a. m.		1.56	1.67	1.73	1.77	1.83	1.85	1.90							
	28	7:03 a. m.	2:17 p. m.	0.93	10:25 a. m.	11:04 a. m.	0.02	0.07	0.10	0.18	0.31	0.51	0.78	0.80	0.85						
Bismarck, N. Dak.	15–16			0.62														(*)			
Block Island, R. I.	13			2.22														0.66			
Boise, Idaho.	21			0.55														0.20			
Boston, Mass.	13			1.09														0.31			
Buffalo, N. Y.	19–20			0.57														(*)			
Burlington, Vt.	5–6			2.05														(*)			
Cairo, Ill.	11			1.67														0.47			
Canton, N. Y.	5			0.52														(*)			
Charles City, Iowa.	25–26			1.40														(*)			
Charleston, S. C.	4			0.71														0.52			
Charlotte, N. C.	28			1.27														0.65			
Chattanooga, Tenn.	12	2:10 a. m.	6:25 a. m.	1.71	3:50 a. m.	4:18 a. m.	0.46	0.06	0.12	0.21	0.36	0.91	0.96								
Cheyenne, Wyo.	27			0.30														(*)			
Chicago, Ill.	11			0.69														0.31			
Cincinnati, Ohio.	16			1.28														0.38			
Cleveland, Ohio.	19–20			0.35														(*)			
Columbia, Mo.	11			1.95														0.56			
Columbia, S. C.	12–13	6:08 p. m.	D. N. a. m.	2.08	6:34 p. m.	7:18 p. m.	0.02	0.09	0.23	0.26	0.36	0.54	0.65	0.70	0.78	0.84					
Columbus, Ohio.	4			0.84														0.27			
Concord, N. H.	12–13			1.17														(*)			
Concordia, Kans.	25			0.28														0.11			
Corpus Christi, Tex.	30			0.04														0.03			
Dallas, Tex.	24	11:25 a. m.	4:00 p. m.	2.36	11:54 a. m.	12:44 p. m.	0.02	0.19	0.31	0.36	0.39	0.47	0.50	0.52	0.55	0.58	0.59				
					12:44 p. m.	1:34 p. m.		0.60	0.61	0.69	0.75	0.77	0.83	0.87	0.98	1.08	1.26				
					1:34 p. m.	2:02 p. m.		1.46	1.66	1.87	2.07	2.21	2.25								
	31	7:18 p. m.	8:45 p. m.	1.02	7:21 p. m.	8:20 p. m.	0.01	0.08	0.21	0.33	0.46	0.52	0.57	0.67	0.72	0.81	0.84	0.99			
Davenport, Iowa.	24–25			1.70														(*)			
Dayton, Ohio.	16			0.93														0.27			
Del Rio, Tex.	24			0.10														0.09			
Denver, Colo.	2–3			0.21														(*)			
Des Moines, Iowa.	11			0.85														0.39			
Detroit, Mich.	28–29			0.57														(*)			
Devils Lake, N. Dak.	15–16			0.25														(*)			
Dodge City, Kans.	25			0.38														0.21			
Drexel, Nebr.	23	4:35 p. m.	D.N.p.m.	1.00	7:06 p. m.	7:46 p. m.	0.10	0.12	0.27	0.33	0.48	0.68	0.73	0.76	0.87						
Dubuque, Iowa.	25–26			1.18														(*)			
Duluth, Minn.	11			0.57														(*)			
Eastport, Me.	13			1.41														0.41			
Elkins, W. Va.	12			0.73														0.31			
Ellendale, N. Dak.	18			0.17														(*)			
El Paso, Tex.	10			0.11														0.10			
Erie, Pa.	11–12			0.53														(*)			
Escanaba, Mich.	28			0.32														0.15			
Eureka, Calif.	13			1.26														0.24			
Evansville, Ind.	11			1.92														0.46			
Flagstaff, Ariz.	26–27			3.11														(*)			
Fort Smith, Ark.	3			0.61														0.52			
Fort Wayne, Ind.	4–5			0.80														(*)			
Fort Worth, Tex.	23–24	8:10 p. m.	2:49 p. m.	2.24	11:46 a. m.	1:00 p. m.	0.19	0.12	0.21	0.33	0.60	0.79	1.04	1.14	1.29	1.41	1.52	1.70	2.05		
	24–25	7:15 p. m.	4:45 a. m.	2.09	9:03 p. m.	9:44 p. m.	0.17	0.10	0.17	0.37	0.43	0.50	0.57	0.67	0.93	0.97					
Fresno, Calif.	21			1.37														0.47			
Galveston, Tex.	4			0.41														0.40			
Grand Haven, Mich.	3–4			1.39														(*)			
Grand Junction, Colo.	2			0.33														(*)			
Grand Rapids, Mich.	28			0.37														0.37			
Green Bay, Wis.	25–26			1.64														(*)			
Greenville, S. C.	17			0.77														0.56			
Hannibal, Mo.	18	8:50 a. m.	12:40 p. m.	1.02	10:10 a. m.	11:01 a. m.	0.15	0.17	0.19	0.21	0.23	0.30	0.43	0.53	0.56	0.59	0.75	0.82			
Harrisburg, Pa.	4–5			1.17														(*)			
Hartford, Conn.	5			0.67														0.30			
Hatteras, N. C.	26			0.86														0.48			
Havre, Mont.	14–15			0.18														(*)			
Helena, Mont.	22–23			0.80														(*)			
Houghton, Mich.	25–26			1.02														(*)			
Houston, Tex.	3	10:35 p. m.	11:55 p. m.	0.93	10:49 p. m.	11:10 p. m.	0.01	0.15	0.38	0.65	0.77	0.79									
Huron, S. Dak.	2–3			0.58														(*)			
Independence, Calif.	1			0.33														(*)			
Indianapolis, Ind.	15			0.48														0.31			
Iola, Kans.	24	10:45 a. m.	3:15 p. m.	1.84	11:12 a. m.	11:40 a. m.	0.07	0.09	0.16	0.22	0.30	0.45	0.50								
Jacksonville, Fla.	4			0.39														0.28			
Kalispell, Mont.	12			0.20														(*)			
Kansas City, Mo.	11			1.03														0.40			
Keokuk, Iowa.	24			0.56														0.25			
Key West, Fla.	22			0.40														0.13			
Knoxville, Tenn.	19			0.81														0.67			
La Crosse, Wis.	25			1.08														0.22			
Lander, Wyo.	10–11			0.18														(*)			
Lansing, Mich.	28	5:05 p. m.	7:10 p. m.	0.64	5:27 p. m.	5:43 p. m.	0.06	0.07	0.30	0.46	0.54										
Lewiston, Idaho.	13			0.13														0.12			
Lexington, Ky.	18			0.95														0.48			
Lincoln, Nebr.	23			0.24														0.24			

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during March, 1920, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.												
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Little Rock, Ark	31–1	7:20 a. m.	D. N. a. m.	2.36	12:56 p. m.	1:28 p. m.	0.52	0.07	0.13	0.19	0.26	0.43	0.55	0.60	.....	.....	.....	.....	.....	.....	.....
Los Angeles, Calif	21	.....	.....	1.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.50	.....	.....	.....
Louisville, Ky	18	.....	.....	1.16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.32	.....	.....	.....
Ludington, Mich	28	.....	.....	0.31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.31	.....	.....	.....
Lynchburg, Va	12	.....	.....	0.41	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.25	.....	.....	.....
Macon, Ga	28	6:35 p. m.	8:10 p. m.	1.38	6:47 p. m.	7:17 p. m.	0.07	0.17	0.62	0.89	0.99	1.06	1.19	.....	.....	.....	.....	.....	.....	.....	.....
Madison, Wis	28	.....	.....	0.68	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.46	.....	.....	.....
Marquette, Mich	3–4	.....	.....	1.40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Memphis, Tenn	31	.....	.....	2.36	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.46	.....	.....	.....
Meridian, Miss	16	2:00 p. m.	2:35 p. m.	0.77	2:07 p. m.	2:23 p. m.	0.04	0.06	0.23	0.64	0.73	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	25	9:25 a. m.	1:01 p. m.	2.02	11:20 a. m.	12: noon	0.13	0.27	0.75	0.99	1.17	1.37	1.50	1.67	1.80	.....	.....	.....	.....	.....	.....
	28	D. N. a. m.	10:55 a. m.	1.14	9:09 a. m.	9:28 a. m.	0.28	0.32	0.40	0.49	0.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Miami, Fla	5	.....	.....	0.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.03	.....	.....	.....
Milwaukee, Wis	25–26	.....	.....	1.43	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Minneapolis, Minn	11	.....	.....	0.77	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Mobile, Ala	4	D. N. a. m.	8:20 a. m.	1.01	4:56 a. m.	5:13 a. m.	0.14	0.12	0.35	0.50	0.53	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Modena, Utah	21–22	.....	.....	0.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Montgomery, Ala	27	9:30 p. m.	D. N. p. m.	0.59	9:42 p. m.	9:56 p. m.	0.04	0.16	0.39	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Moorhead, Minn	16	.....	.....	0.16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Mount Tamalpais, Calif	15	.....	.....	0.93	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.22	.....	.....	.....
Nantucket, Mass	13	.....	.....	0.88	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.24	.....	.....	.....
Nashville, Tenn	18–19	.....	.....	1.31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.61	.....	.....	.....
New Haven, Conn	29	.....	.....	0.77	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.30	.....	.....	.....
New Orleans, La	12	9:18 a. m.	10:45 a. m.	1.17	9:20 a. m.	10:07 a. m.	0.01	0.10	0.26	0.31	0.35	0.41	0.59	0.76	0.96	1.10	1.14	.....	.....	.....	.....
New York, N. Y	5	.....	.....	2.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.64	.....	.....	.....
Norfolk, Va	13	.....	.....	1.07	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.31	.....	.....	.....
Northfield, Vt	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
North Head, Wash	3	.....	.....	0.37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.08	.....	.....	.....
North Platte, Nebr	3	.....	.....	0.18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Oklahoma, Okla	10	8:37 p. m.	10:50 p. m.	0.64	9:11 p. m.	9:31 p. m.	0.01	0.05	0.14	0.38	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	24	7:50 a. m.	9:25 a. m.	1.05	8:38 a. m.	9:08 a. m.	0.09	0.06	0.18	0.40	0.62	0.79	0.88	.....	.....	.....	.....	.....	.....	.....	.....
Omaha, Nebr	3	.....	.....	0.28	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Oswego, N. Y	5	.....	.....	0.69	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Palestine, Tex	24–25	9:10 p. m.	D. N. a. m.	0.96	1:26 a. m.	1:43 a. m.	0.24	0.13	0.29	0.50	0.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Parkersburg, W. Va	16	.....	.....	0.79	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.32	.....	.....	.....
Pensacola, Fla	4	.....	.....	0.48	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.33	.....	.....	.....
Peoria, Ill	25	.....	.....	1.65	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.35	.....	.....	.....
Philadelphia, Pa	5	.....	.....	1.40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28	.....	.....	.....
Phoenix, Ariz	10	.....	.....	0.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.38	.....	.....	.....
Pierre, S. Dak	2–3	.....	.....	0.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Pittsburgh, Pa	12	.....	.....	0.28	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.23	.....	.....	.....
Pocatello, Idaho	2	.....	.....	0.36	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.15	.....	.....	.....
Point Reyes Light, Calif	9	.....	.....	0.33	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.15	.....	.....	.....
Port Angeles, Wash	13	.....	.....	0.34	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.10	.....	.....	.....
Port Huron, Mich	12	.....	.....	0.42	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Portland, Me	6	.....	.....	2.78	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.26	.....	.....	.....
Portland, Oreg	13	.....	.....	0.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.27	.....	.....	.....
Providence, R. I	12–13	.....	.....	1.19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Pueblo, Colo	3	.....	.....	0.07	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Raleigh, N. C	5	.....	.....	0.71	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28	.....	.....	.....
Rapid City, S. Dak	2	.....	.....	0.16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Reading, Pa	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Red Bluff, Calif	9	.....	.....	1.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.59	.....	.....	.....
Reno, Nev	25	.....	.....	0.31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Richmond, Va	19	.....	.....	1.30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.39	.....	.....	.....
Rochester, N. Y	19–20	.....	.....	0.65	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Roseburg, Oreg	24	.....	.....	0.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.14	.....	.....	.....
Roswell, N. Mex	11–12	.....	.....	0.12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.12	.....	.....	.....
Sacramento, Calif	21	.....	.....	0.89	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.26	.....	.....	.....
Saginaw, Mich	28	.....	.....	0.29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28	.....	.....	.....
St. Joseph, Mo	24	D. N. a. m.	9:30 a. m.	2.56	5:27 a. m.	5:57 a. m.	0.26	0.07	0.18	0.21	0.28	0.43	0.59	.....	.....	.....	.....	.....	.....	.....	.....
					8:16 a. m.	8:54 a. m.	1.21	0.08	0.19	0.48	0.70	0.74	0.92	1.16	1.32	.....	.....	.....	.....	.....	.....
	24	12:36 p. m.	4:55 p. m.	1.06	1:04 p. m.	1:30 p. m.	0.07	0.07	0.11	0.24	0.42	0.61	0.65	.....	.....	.....	.....	.....	.....	.....	.....
St. Louis, Mo	11	.....	.....	1.11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.57	.....	.....	.....
St. Paul, Minn	18–19	.....	.....	0.85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Salt Lake City, Utah	25–26	.....	.....	1.27	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
San Antonio, Tex	24	.....	.....	0.47	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.35	.....	.....	.....
San Diego, Calif	10	.....	.....	0.57	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.29	.....	.....	.....
Sand Key, Fla.§	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sandusky, Ohio	16	.....	.....	0.28	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Sandy Hook, N. J	5	.....	.....	1.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.42	.....	.....	.....
San Francisco, Calif	9	.....	.....	0.95	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.51	.....	.....	.....
San Jose, Calif	21	.....	.....	1.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.24	.....	.....	.....
San Luis Obisque, Calif	9	.....	.....	0.89	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.43	.....	.....	.....
Santa Fe, N. Mex	10	.....	.....	0.29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Sault Ste. Marie, Mich	25–26	.....	.....	1.18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Savannah, Ga	4	.....	.....	1.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.49	.....	.....	.....
Scranton, Pa	5–6	.....	.....	†2.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Seattle, Wash	13	.....	.....	1.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28	.....	.....	.....
Sheridan, Wyo	10–11	.....	.....	0.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Shreveport, La	3	8:20 p. m.	11:00 p. m.	1.18	9:34 p. m.	10:20 p. m.	0.21	0.11	0.17	0.24	0.49	0.52	0.64	0.73	0.79	0.85	0.88	.....	.....	.....	.....
	24–25	7:20 p. m.	8:00 a. m.	0.79	4:11 a. m.	4:23 a. m.	0.15	0.26	0.58	0.60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sioux City, Iowa	28	.....	.....	1.02	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Spokane, Wash	4	.....	.....	0.30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Springfield, Ill	11–12	.....	.....	2.30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Springfield, Mo	11	7:41 a. m.	7:42 p. m.	1.69	2:04 p. m.	2:28 p. m.	0.48	0.16	0.26	0.35	0.55	0.69	.....	.....	.....	.....	.....	.....	.....	.....	.....
Syracuse, N. Y	5	.....	.....	0.79	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Tacoma, Wash	8	.....	.....	0.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.19	.....	.....	.....
Tampa, Fla	4	.....	.....	0.39	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.22	.....	.....	.....
Tatoosh Island, Wash	12	.....	.....	1.92	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28	.....	.....	.....
Taylor, Tex	24–25	.....	.....	0.76	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.37	.....	.....	.....
Terre Haute, Ind	15	.....	.....	0.33	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.31	.....	.....	.....
Thomasville, Ga	12–13	9:15 p. m.	D. N. a. m.	1.21	10:51 p. m.	11:50 p. m.	0.14	0.08	0.23	0.35	0.48	0.57	0.58	0.60	0.64	0.73	0.81	1.00	.....	.....	.....
Toledo, Ohio	28	.....	.....	0.27	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.27	.....	.....	.....
Tonopah, Nev	21	.....	.....	0.36	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month. § Gage down.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded in 0.25 inch any 5 minutes, or 0.80 in 1 hour, during March, 1920, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Topeka, Kans.	11	3:02 p. m.	9:30 p. m.	0.92	4:46 p. m.	5:12 p. m.	0.20	0.20	0.26	0.30	0.42	0.56	0.58	.....	.....	.....	.....	.....	.....	.....	.....
	24	5:15 a. m.	6:59 a. m.	1.11	6:03 a. m.	6:49 a. m.	0.12	0.17	0.28	0.39	0.46	0.53	0.59	0.69	0.77	0.89	0.96	.....	.....	.....	.....
Trenton, N. J.	5	.....	.....	1.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.29	.....	.....	.....
Valentine, Nebr.	27–28	.....	.....	0.33	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Vicksburg, Miss.	19	3:40 a. m.	5:20 a. m.	0.79	4:02 a. m.	4:11 a. m.	0.02	0.31	0.62	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Walla Walla, Wash.	12	.....	.....	0.59	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.09	.....	.....	.....
Washington, D. C.	5	.....	.....	0.89	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.22	.....	.....	.....
Wausau, Wis.	28	.....	.....	0.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Wichita, Kans.	25	.....	.....	1.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.25	.....	.....	.....
Williston, N. Dak.	15–16	.....	.....	1.22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Wilmington, N. C.	5	.....	.....	1.37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.46	.....	.....	.....
Winnemucca, Nev.	1	.....	.....	0.90	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.28	.....	.....	.....
Wytheville, Va.	19	.....	.....	1.04	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.35	.....	.....	.....
Yankton, S. Dak.	3	.....	.....	0.94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....
Yellowstone Park, Wyo.	30–31	.....	.....	0.41	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(*)	.....	.....	.....

* Self-register not in use.

TABLE III.—*Data furnished by the Canadian Meteorological Service, March, 1920.*

Stations.	Altitude above mean sea level Jan. 1, 1919.	Pressure.			Temperature of the air.						Precipitation.		
		Station reduced to mean of 24 hours.	Sea level reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Feet.	*Inches.*	*Inches.*	*Inches.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, N. F.	125	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sydney, C. B. I.	48	29.82	29.87	−.01	31.1	+4.9	40.3	21.9	65	− 2	2.87	−2.06	7.5
Halifax, N. S.	88	29.78	29.89	−.05	32.8	+3.8	41.1	24.4	68	−10	4.15	−1.31	9.7
Yarmouth, N. S.	65	29.82	29.89	−.06	33.6	+2.8	40.4	26.9	58	2	3.19	−1.66	3.7
Charlottetown, P. E. I.	38	29.79	29.83	−.07	29.2	+3.8	36.2	22.2	58	− 7	5.01	+1.80	10.5
Chatham, N. B.	28	29.81	29.84	−.06	27.0	+4.0	39.1	14.8	67	−22	3.63	+0.16	13.4
Father Point, Que.	20	29.78	29.81	−.09	24.3	+4.0	32.5	16.1	56	−10	1.52	−1.21	11.2
Quebec, Que.	296	29.54	29.87	−.09	25.7	+4.5	34.6	16.9	60	−18	4.02	+0.76	19.5
Montreal, Que.	187	29.68	29.90	−.10	30.2	+6.4	37.1	22.3	60	− 7	4.33	+0.54	27.9
Stonecliffe, Ont.	489	29.27	29.90	−.11	24.4	+5.4	39.5	9.4	70	−18	1.87	−0.19	3.7
Ottawa, Ont.	236	29.66	29.94	−.07	29.4	+7.9	39.5	19.3	66	−18	2.38	−0.34	9.1
Kingston, Ont.	285	29.60	29.92	−.09	30.6	+5.0	39.0	22.2	63	− 6	1.60	−1.04	7.9
Toronto, Ont.	379	29.52	29.95	−.07	33.8	+6.5	43.1	24.6	66	− 1	2.31	−0.33	5.9
Cochrane, Ont.	930	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
White River, Ont.	1,244	28.44	29.79	−.24	17.0	+4.8	32.6	1.5	55	−42	2.29	+0.91	13.8
Port Stanley, Ont.	592	29.32	29.98	−.05	32.2	+5.0	40.5	24.0	59	5	1.90	−0.90	2.8
Southampton, Ont.	656	29.16	.....	.....	29.4	+4.7	39.2	19.6	66	−12	1.91	−0.74	10.2
Parry Sound.	688	29.19	29.90	− 12	27.6	+6.5	37.7	17.5	58	−12	1.22	−1.01	6.4
Port Arthur, Ont.	644	29.11	29.84	−.21	22.8	+6.0	33.0	12.6	52	−11	1.44	+0.47	9.3
Winnipeg, Man.	760	28.99	29.85	−.24	18.0	+5.7	28.8	7.2	50	−19	1.47	+0.44	14.4
Minnedosa, Man.	1,690	27.98	29.87	−.19	13.7	+1.2	25.7	1.7	50	−28	0.96	+0.31	9.6
Le Pas, Man.	860	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Qu'Appelle, Sask.	2,115	27.50	29.82	−.22	17.1	+2.2	27.2	7.1	47	−24	1.60	+0.83	15.6
Medicine Hat, Alb.	2,144	27.46	29.77	−.23	27.4	−0.1	37.3	17.4	62	−24	0.97	+0.21	8.5
Moose Jaw, Sask.	1,759	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Swift Current, Sask.	2,392	27.14	29.83	−.19	23.4	+1.4	32.8	14.0	54	−22	0.32	−0.49	3.2
Calgary, Alb.	3,428	26.18	29.85	−.10	24.3	−1.9	36.2	12.4	56	−22	0.37	−0.35	3.7
Banff, Alb.	4,521	25.13	29.83	−.11	22.4	+2.2	33.6	11.1	51	−24	1.46	+0.05	14.4
Edmonton, Alb.	2,150	27.48	29.83	−.13	20.2	−4.0	31.4	9.1	50	−28	1.26	+0.54	12.6
Prince Albert, Sask.	1,450	28.26	29.90	−.18	16.5	+4.5	28.4	4.6	46	−25	1.30	+0.53	13.0
Battleford, Sask.	1,592	28.06	29.86	−.20	18.1	+5.0	28.3	7.8	50	−25	0.70	+0.14	7.0
Kamloops, B. C.	1,262	28.58	29.90	−.02	38.4	+2.3	48.3	28.6	60	13	0.18	−0.39	0.7
Victoria, B. C.	230	29.63	29.89	−.08	43.9	+2.0	49.6	38.2	59	32	2.28	−0.84	0.4
Barkerville, B. C.	4,180	25.41	29.76	−.12	25.2	−0.9	33.6	16.8	44	− 9	3.61	+1.72	36.1
Triangle Island, B. C.	680	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Prince Rupert, B. C.	170	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Hamilton, Bermuda.	151	30.00	30.17	+.09	62.5	+0.3	68.1	57.0	73	53	10.05	+4.92	.....

SEISMOLOGICAL REPORTS.

W. J. HUMPHREYS, Professor in Charge.

[Dated: Weather Bureau, Washington, D. C., May 3, 1920.]

TABLE I.—*Noninstrumental earthquake reports, March, 1920.*

Day.	Approximate time, Greenwich civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
		CALIFORNIA.								
1920.	*H. m.*		° ′	° ′			*Sec.*			
Mar. 4	3 25	El Segundo	33 56	118 22	4	1	Several..	Loud rumbling....	Felt by many.....	Associated Press.
		Manhattan Beach	33 52	118 22	4	1	...do.....	.....do.....	.....do.....	Do.
		Redondo Beach	33 50	118 22	4	1	...do.....	.....do.....	.....do.....	Do.
9	5 50	Calexico	32 41	115 30	3	1	5	None.....	Felt by several.....	H. M. Rouse.
18	13 40	Hemet	33 45	116 58	2	1	2	Faint.....	.....do.....	C. E. McManigal.
20	7 04	San Luis Obispo	35 13	120 45	2	1	2	None.....	.....do.....	J. E. Hissong.
20	17 30	Blocksburg	40 17	123 39	4	1	.....	.....do.....	.....do.....	Humboldt Times.
		Eureka	40 45	124 15	4	1	20	.....do.....	Windows rattled.....	J. M. Jones.
		WASHINGTON.								
2	4 20	Glenoma	46 30	122 07	4	1	.....	Faint rumbling...	Dishes rattled.....	J. A. Ulsh.

TABLE 2.—*Instrumental reports, March, 1920.*

[For significance of symbols and abbreviations, and for a description of stations and instruments, see the REVIEW for January, 1920, pp. 62-63.]

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
		ARIZONA. *U. S. C. & G. S. Magnetic Observatory, Tucson.*						
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 20	.....	eP_E....	17 54 35	.....	.....	.....	.....	
		eN.....	17 56 05	.....	.....	.....	.....	
		S_E....	17 56 35	5	10	.....	.....	
		F_E....	18 01 ..	.....	.....	.....	.....	
		F_N....	17 58 ..	.....	.....	.....	.....	
20	.....	e_E.....	18 51 21	.....	.....	.....	.....	Nothing on N.
		L_E....	18 59 00	.....	.....	.....	.....	
		M_E....	19 00 30	.....	20	.....	.....	
		F_E....	19 34 ..	.....	.....	.....	.....	
23	.....	P_E....	15 26 49	3	.....	.....	.....	N not in good adjustment.
		P_N....	15 26 55	.....	.....	.....	.....	
		L_E....	15 33 44	.....	.....	.....	.....	
		L_N....	15 34 19	.....	.....	.....	.....	
		M_E....	15 34 32	4	30	.....	.....	
		M_N....	15 34 22	.....	.....	20	.....	
		C_E....	15 37 15	.....	.....	.....	.....	
		F_E....	15 41 ..	.....	.....	.....	.....	
		F_N....	15 37 ..	.....	.....	.....	.....	
29	.....	iP_E....	5 31 21	3	.....	.....	.....	S and L not well defined. N not in good adjustment.
		P_N....	5 13 22	.....	.....	.....	.....	
		eS_E....	5 17 47	.....	.....	.....	.....	
		eL_E....	5 21 10	.....	.....	.....	.....	
		eL_N....	5 23 14	.....	.....	.....	.....	
		M.....	5 23 30	12	130	60	.....	
		C_E....	5 28 ..	8	.....	.....	.....	
		C_N....	5 25 ..	.....	.....	.....	.....	
		F_E....	5 54 ..	8	.....	.....	.....	
		F_N....	5 27 ..	.....	.....	.....	.....	
		COLORADO. *Sacred Heart College, Denver.*						
1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 13	.....	.....	.....	.....	.....	.....	.....	Visible activity and irregular waves from 12 to 15.
20	.....	L_N....	17 56 ..	.....	.....	.....	.....	
		L_E....	17 57 ..	.....	.....	.....	.....	
		M_N....	17 57 ..	7	.....	*3,500	.....	
		M_E....	(?)	.....	.....	.....	.....	
		F.....	18	.....	.....	.....	.....	
21	.....	.....	.....	.....	.....	.....	.....	Activity at intervals during day.
24	.....	.....	.....	.....	.....	.....	.....	Wavelets at intervals during day. Somewhat doubtful as to being seismic.
29	.....	P.....	5 12 ..	.....	.....	.....	.....	Preliminaries not distinct.
		S.....	5 16 ..	.....	.....	.....	.....	
		L.....	5 20 ..	.....	.....	.....	.....	
		M_N....	5 22 ..	8	.....	*2,000	.....	
		M_E....	5 22 ..	12	*3,000	.....	.....	
		C_N....	5 23 ..	.....	.....	.....	.....	
		C_E....	5 26 ..	.....	.....	.....	.....	
		F.....	5 36 ..	.....	.....	.....	.....	

*Trace amplitude.

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

DISTRICT OF COLUMBIA. *Georgetown University, Washington.*

1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 10	.....	e_E.....	16 30 03	.....	.....	.....	.....	
		e_N.....	16 30 08	.....	.....	.....	.....	
		F.....	16 35 ..	.....	.....	.....	.....	
15	.....	L_E....	13 04 09	22	.....	.....	.....	Sheets changed at 13h. 15m., quake still on. Early phases lost in micros.
		L_N....	13 05 09	22	.....	.....	.....	
19	.....	e_E.....	17 55 ..	.....	.....	.....	.....	
		e_N.....	17 55 ..	.....	.....	.....	.....	
		F.....	18 03 ..	.....	.....	.....	.....	
20	.....	e_E?....	18 04 27	.....	.....	.....	.....	Heavy micros. F in second quake.
		e_N?....	18 04 05	.....	.....	.....	.....	
		S_E....	18 08 05	.....	.....	.....	.....	
		S_N....	18 08 05	.....	.....	.....	.....	
		eL_E...	18 10 18	9	.....	.....	.....	
		eL_N...	18 09 48	9	.....	.....	.....	
		L_E....	18 11 05	13	.....	.....	.....	
				VERTICAL.				
		eL_Z...	*18 10 18*	.....	.....	.....	.....	F lost in second quake.
		L_Z....	*18 14 17*	*17*	.....	.....	.....	
20	.....	eP_E...	18 43 33	.....	.....	.....	.....	
		eP_N...	18 43 26	.....	.....	.....	.....	
		eS_E....	18 53 43	.....	.....	.....	.....	
		iS_N....	18 53 40	.....	.....	.....	.....	
		eL_E...	19 07 12	16	.....	.....	.....	
		eL_N...	19 07 30	16	.....	.....	.....	
		L_E....	19 11 11	28	.....	.....	.....	
		L_N....	19 12 00	27	.....	.....	.....	
		F.....	21 *ca.* ..	.....	.....	.....	.....	
				VERTICAL.				
		eP_Z...	*18 43 18*	.....	.....	.....	.....	No distinct M.
		S_Z?...	*18 53 49*	.....	.....	.....	.....	
		eL_Z...	*19 07 12*	*14*	.....	.....	.....	
		L_Z....	*19 15 00*	*16*	.....	.....	.....	
		F.....	*20 ca.* ..	.....	.....	.....	.....	
22	.....	L_E....	{20 58 00 to 21 01 00}	21	.....	.....	.....	
23	.....	eP_E...	15 28 05	.....	.....	.....	.....	No distinct M.
		eP_N...	15 28 05	.....	.....	.....	.....	
		S_E....	15 33 07	.....	.....	.....	.....	
		S_N....	15 33 07	.....	.....	.....	.....	
		eL_E...	15 35 42	.....	.....	.....	.....	
		eL_N...	15 35 42	.....	.....	.....	.....	
		L_N....	15 41 04	10	.....	.....	.....	
		F.....	15 50 ..	.....	.....	.....	.....	
29	.....	eP_E...	5 15 15	.....	.....	.....	.....	S_N not discernible. Record from Maika Machine—V, A_N 59, A_E 47, To 9.0.
		eP_N...	5 15 33	.....	.....	.....	.....	
		eS_E....	5 21 05	.....	.....	.....	.....	
		eL_E...	5 24 24	9	.....	.....	.....	
		eL_N...	5 24 30	8	.....	.....	.....	
		M_{E1}...	5 29 51	11	*10,900	.....	.....	
		M_N....	5 31 57	13	.....	*2,400	.....	
		M_{E2}...	5 31 54	13	*13,500	.....	.....	
		F.....	6 40 ..	.....	.....	.....	.....	
				VERTICAL.				
		eP_Z...	*5 15 15*	.....	.....	.....	.....	eL_Z doubtful.
		eS_Z...	*5 21 27*	.....	.....	.....	.....	
		M_Z....	*5 31 31*	*13*	*2,700	.....	.....	
		F_Z....	*6 35* ..	.....	.....	.....	.....	

*Trace amplitude.

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.*

1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 9	.....	eL.....	4 50 ..	16	.....	.....	.....	Nothing on E-W.
		F.....	4 55 *ca*	.....	.....	.....	.....	
15	.....	eL.....	13 03 ..	20	.....	.....	.....	
		F.....	13 20 *ca*	.....	.....	.....	.....	
19	.....	e.....	17 55 ..	.....	.....	.....	.....	
		F.....	18 10 ..	.....	.....	.....	.....	
20	.....	e.....	18 03 ..	.....	.....	.....	.....	Confused by micros.
		F.....	18 20 ..	.....	.....	.....	.....	
20	.....	eP?....	18 43 30	.....	.....	.....	9,000?	
		S.....	18 53 43	.....	.....	.....	.....	
		L.....	19 07 06	.....	.....	.....	.....	
		L.....	19 12 ..	24	.....	.....	.....	
		L.....	19 14 ..	.....	.....	.....	.....	
		F.....	19 25 *ca*	.....	.....	.....	.....	
23	.....	eP.....	15 27 25	.....	.....	.....	.....	No distinct L. Record much confused; appearance of 2d quake, P 15-34-10, superimposed.
		S?.....	15 32 40	.....	.....	.....	.....	
		F.....	16 *ca*.	.....	.....	.....	.....	
29	.....	P.....	5 15 00	.....	.....	.....	4,200	L not defined.
		S.....	5 21 *ca*	.....	.....	.....	.....	
		M.....	5 29 40	.....	.....	*22,000	.....	
		M.....	5 33 30	.....	.....	*30,000	.....	
		F.....	6 35 *ca*	.....	.....	.....	.....	

* Trace amplitude.

ILLINOIS. *U. S. Weather Bureau, Chicago.*

1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 1	.....	eL.....	11 46 40	20	.....	.....	.....	
		L.....	12 02 ..	15	.....	.....	.....	
		F.....	12 20 *ca*	.....	.....	.....	.....	
9	.....	P?.....	4 40 27	.....	.....	.....	3,000?	P not well defined.
		S.....	4 45 12	.....	.....	.....	.....	
		L.....	4 47 12	.....	.....	.....	.....	
		F.....	5 10 *ca*	.....	.....	.....	.....	
10	.....	e.....	16 27 05	.....	.....	.....	.....	Very feeble; possibly not seismic.
		L?.....	16 30 20	.....	.....	.....	.....	
		F.....	16 35 *ca*	.....	.....	.....	.....	
15	.....	P.....	12 32 20	.....	.....	.....	5,000	
		S.....	12 39 20	.....	.....	.....	.....	
		L.....	12 53 ..	30	.....	.....	.....	
		L.....	13	22	.....	.....	.....	
		F.....	13 40 *ca*	.....	.....	.....	.....	
17	.....	iP.....	19 00 00	.....	.....	.....	11,800	
		S?.....	19 12 12	.....	.....	.....	.....	
		eL.....	19 46 ..	.....	.....	.....	.....	
		L.....	19 57 ..	20	.....	.....	.....	
		F.....	20 30 *ca*	.....	.....	.....	.....	
19	.....	e.....	17 51 10	.....	.....	.....	.....	
		L?.....	17 55 ..	.....	.....	.....	.....	
		F.....	18 20 *ca*	.....	.....	.....	.....	
20	.....	P.....	17 59 10	.....	.....	.....	1,600?	
		S?.....	18 01 55	.....	.....	.....	.....	
		L.....	18 03 08	.....	.....	.....	.....	
		F.....	18 30 *ca*	.....	.....	.....	.....	
20	.....	iP.....	18 43 37	.....	.....	.....	8,700	
		S.....	18 53 35	.....	.....	.....	.....	
		L.....	19 07 ..	22	.....	.....	.....	
		L.....	19 23 ..	15	.....	.....	.....	
		F.....	21 40 *ca*	.....	.....	.....	.....	
22	.....	e.....	0 15 20	.....	.....	.....	.....	
		eL.....	0 20 ..	18	.....	.....	.....	
		F.....	0 35 ..	.....	.....	.....	.....	
22	.....	eL.....	2 33 ..	22	.....	.....	.....	
		L.....	2 38 ..	18	.....	.....	.....	
		F.....	3 20 *ca*.	.....	.....	.....	.....	
22	.....	e.....	20 22 ..	.....	.....	.....	.....	
		L.....	20 52 ..	22	.....	.....	.....	
		L.....	20 58 ..	16	.....	.....	.....	
		L.....	21 04 ..	16	.....	.....	.....	
		F.....	22 *ca*.	.....	.....	.....	.....	
23	.....	iP.....	15 27 24	.....	.....	.....	.....	
		S.....	15 31 58	.....	.....	.....	.....	
		L.....	15 36 30	30	.....	.....	.....	
		F.....	16 20 *ca*.	.....	.....	.....	.....	
29	.....	iP.....	5 14 08	.....	.....	.....	3,200	
		S.....	5 19 08	.....	.....	.....	.....	
		L.....	5 22 ..	.....	.....	.....	.....	
		M.....	5 25 ..	.....	*13,000	.....	.....	
		F.....	7 20 *ca*.	.....	.....	.....	.....	

* Trace amplitude.

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

MARYLAND. *U. S. C. & G. S. Magnetic Observatory, Cheltenham.*

1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 20	.....	e_E.....	17 57 36	.....	.....	.....	.....	Phases indefinite, except S_N.
		eS_N...	18 08 00	.....	.....	20	.....	
		F_E.....	18 13 ..	.....	.....	.....	.....	
		F_N.....	18 14 ..	.....	.....	.....	.....	
20	.....	P_N.....	18 43 52	.....	.....	.....	.....	Micros obscure record on E-W.
		S_E.....	18 53 45	.....	.....	.....	.....	
		S_N.....	18 53 50	.....	.....	.....	.....	
		L_N.....	19 12 15	26	.....	.....	.....	
		M_N.....	19 15 48	17	10	80	.....	
		C_N.....	19 19 ..	15	.....	.....	.....	
		F_E.....	19 07 ..	.....	.....	.....	.....	
		F_N.....	19 43 ..	.....	.....	.....	.....	
23	.....	P_E.....	15 27 49	.....	.....	.....	.....	Waves irregular, phases uncertain.
		eP_N...	15 28 12	.....	.....	.....	.....	
		eS_E...	15 33 00	.....	.....	.....	.....	
		eS_N...	15 33 09	.....	.....	.....	.....	
		L_E.....	15 37 17	.....	10	.....	.....	
		eL_N...	15 37 20	.....	.....	20	.....	
		C_E.....	15 40 30	.....	.....	.....	.....	
		C_N.....	15 41 45	10	.....	.....	.....	
		L_E.....	15 45 ..	.....	.....	.....	.....	
		L_N.....	15 55 ..	9	.....	.....	.....	
29	.....	eP_E...	5 15 13	.....	.....	.....	.....	
		eP_N...	5 15 15	.....	.....	.....	.....	
		eS_N...	5 24 07	6	.....	.....	.....	
		L_E.....	5 28 58	.....	.....	.....	.....	
		L_N.....	5 28 20	20	.....	.....	.....	
		M_E.....	5 31 48	.....	100	.....	.....	
		M_N.....	5 31 50	13	.....	400	.....	
		C.....	5 37 ..	7	.....	.....	.....	
		F_E.....	5 51 ..	7	.....	.....	.....	
		F_N.....	6 08 ..	7	.....	.....	.....	

MASSACHUSETTS. *Harvard University, Cambridge.*

1920.			*H. m. s.*	*Sec.*	μ	μ	*Km.*	
Mar. 15	.....	O?.....	12 10 *ca*.	.....	.....	.....	11,955?	P and S masked by microseisms and too much entangled to be read on N-S.
		e_E?...	12 35 11	.....	.....	.....	.....	
		S_E?...	12 36 59	6	.....	.....	.....	
		e_E.....	12 42 07	12	.....	.....	.....	
		eL_E...	12 02 32	36	.....	.....	.....	
		L.....	13 05 43	20	.....	.....	.....	
		L.....	13 15 06 to 25 14	14	.....	.....	.....	
		F_E?...	14 *ca*.	.....	.....	.....	.....	
20	.....	O.....	18 00 37	.....	.....	.....	2,140	
		P_N?...	18 05 15	4	.....	.....	.....	
		P_E.....	18 05 23	.....	.....	.....	.....	
		i_N.....	18 05 26	2	.....	.....	.....	
		e_N.....	18 06 46	.....	.....	.....	.....	
		S_N.....	18 08 50	6	.....	.....	.....	
		i_E.....	18 09 22	6	.....	.....	.....	
		eL_N?..	18 10 10	12	.....	.....	.....	
		L_E.....	18 11 53	10	.....	.....	.....	
		M_N.....	18 12 11	.....	.....	.....	.....	
		L_E.....	18 12 46	15	.....	.....	.....	F in microseisms
		F_E.....	18 20 *ca*.	.....	.....	.....	.....	
		F_N.....	18 24 *ca*.	.....	.....	.....	.....	
20	.....	O.....	18 29 30	.....	.....	.....	10,600	95°.4 of arc.
		P_N.....	18 43 01	.....	.....	.....	.....	
		eP_E...	18 44 02	.....	.....	.....	.....	
		S_N.....	18 54 25	16	.....	.....	.....	iN-iS
		S_E.....	18 54 29	7	.....	.....	.....	iN-iS
		i_N.....	18 55 26	14	.....	.....	.....	
		i_E.....	18 55 32	.....	.....	.....	.....	If O_2 was set off by iS of O_1, distance between epicentres would be 13,000 km. *ca*.
		S_{EN}?..	19 00 20	10	.....	.....	.....	
		eL_E...	19 06 40	44	.....	.....	.....	
		L_N.....	19 12 29	37	.....	.....	.....	
		eM_N...	19 13 06	21	.....	.....	.....	
		M_N.....	19 15 46	22	.....	*6,225	.....	
		C_N.....	19 21 35	.....	.....	.....	.....	
		F_N.....	20 10 *ca*.	.....	.....	.....	.....	F masked by micros.
		M_E.....	20 43 46	.....	.....	.....	.....	
		F_E.....	20 51 *ca*.	.....	.....	.....	.....	
22	.....	O?.....	19 07 *ca*.	.....	.....	.....	11,370?	Distance on supposition that M_{rept} was registered as given. Record indistinct on E-W.
		e_E.....	19 54 10	.....	.....	.....	.....	
		eL_E...	19 57 10	10–23	.....	.....	.....	
		L.....	20 00 49	15–16	.....	.....	.....	
		F?.....	20 30 00	.....	.....	.....	.....	
		M_{rl}...	21 22 11	14	.....	.....	.....	
		F.....	21 24 18	.....	.....	.....	.....	
23	.....	O?.....	15 08 00	.....	.....	.....	5,760?	51°.8 of arc. E-W record difficult to diagnose into S and L waves. First phases of N-S masked by micros.
		S_N.....	15 24 39	7	.....	.....	.....	
		e.....	15 28 02	8	.....	.....	.....	
		eL_N...	15 33 16	20	.....	.....	.....	
		L.....	15 34 11	20	.....	.....	.....	
		L_E.....	15 38 32	40	.....	.....	.....	Distance from eLn 15-33-16 and S 15-24-39. Distance would be 7,845 by L 40s period.
		M_E?...	15 41 40	20	.....	.....	.....	
		C_E.....	15 43 *ca*.	15	.....	.....	.....	
		F.....	16 27 *ca*.	.....	.....	.....	.....	

* Trace amplitude.

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

MASSACHUSETTS. *Harvard University, Cambridge*—Continued.

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 28	.....	O?....	13 ca.	.....	.....	.....	.....	Record masked by micros of 8 sec. period. Possibly not seismic.
		eN?...	13 13 09	.....	.....	.....	.....	
		eN?...	13 21 22	6	.....	.....	.....	
		eN....	13 35 09	8	.....	.....	.....	
		e_E....	13 36 06	.....	.....	.....	.....	
		e_N....	13 36 51	6	.....	.....	.....	
		e_E....	13 44 24	.....	.....	.....	.....	
		L_N?...	13 53 02	22	.....	.....	.....	Then 15.
		e_E....	13 53 45	8	.....	.....	.....	
		L_E?...	13 58 15	26	.....	.....	.....	
		e_E....	14 01 23	8	.....	.....	.....	
		F_E....	14 14 ca.	.....	.....	.....	.....	
28	.....	O?....	23 06 38	.....	.....	.....	4,270?	38° .4 of arc.
		eP_E?..	23 14 16	.....	.....	.....	.....	
		P.....	23 14 21	.....	.....	.....	.....	
		P_{rl}?...	23 15 48	.....	.....	.....	.....	P_{rl}–eP gives distance 4,625 km.
		S_E....	23 20 18	6	.....	.....	.....	
		eL_E...	23 26 02	38	.....	.....	.....	N record masked by micros and tangled lines; stylus left drum in M13h-30-25.
		M_E....	23 28 03	.....	*4,000	.....	.....	
		M_E....	23 31 05	.....	*12,000	.....	.....	
		C_E....	23 32 00	.....	.....	.....	.....	
29	.....	F.....	0 39 ca.	.....	.....	.....	.....	

* Trace amplitude.

NEW YORK. *Cornell University, Ithaca.*

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 15	.....	eL_N...	13 03 25	22	.....	.....	.....	
		eL_E...	13 04 25	20	.....	.....	.....	
		F.....	13 24 ..	.....	.....	.....	.....	
20	.....	e_N....	18 04 ..	12	.....	.....	.....	Short period waves.
		F.....	18 18 ..	.....	.....	.....	.....	
20	.....	eP_N...	18 43 39	4	.....	.....	.....	
		Pr_{1N}..	18 47 04	6	.....	.....	.....	
		S_E....	18 53 54	11	.....	.....	.....	
		S_N....	18 54 04	10	.....	.....	.....	
		L?.....	19 06 02	20	.....	.....	.....	
		L_E....	19 08 25	28	.....	.....	.....	
		F.....	20 17 ..	.....	.....	.....	.....	
23	.....	e.....	15 34 52	7	.....	.....	.....	
		L_N....	15 39 22	27	.....	.....	.....	
		F.....	16 01 ..	.....	.....	.....	.....	
29	.....	P.....	5 15 02	4	.....	.....	.....	
		S.....	5 20 50	7	.....	.....	.....	
		L.....	5 26 ..	28	.....	.....	.....	
		F.....	6 25 ..	.....	.....	.....	.....	

CANAL ZONE. *Panama Canal, Balboa Heights.*

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 5	.....	.....	.....	.....	.....	.....	.....	Very slight tremor at 1-41-00; distance and direction unknown.
6	.....	.....	.....	.....	.....	.....	.....	Very slight tremor at 7-30-30; distance and direction unknown.
7	.....	.....	.....	.....	.....	.....	.....	Very slight tremor at 15-55-20; distance and direction unknown.
16	.....	P.....	4 06 29	.....	.....	.....	212	Dir. probably SW.
		S.....	4 06 52	.....	.....	.....	.....	
		M.....	4 07 00	.....	*3,000	*1,500	.....	
		F_E....	4 10 20	.....	.....	.....	.....	
		F_N....	4 10 30	.....	.....	.....	.....	
19	.....	P_E....	1 44 38	.....	.....	.....	85	Dir. probably W or SW.
		P_N....	1 44 40	.....	.....	.....	.....	
		S_E....	1 44 48	.....	.....	.....	.....	
		S_N....	1 44 50	.....	.....	.....	.....	
		M_E....	1 44 49	.....	*10,500	.....	.....	
		M_N....	1 44 52	.....	.....	*3,500	.....	
		F_E....	1 45 35	.....	.....	.....	.....	
		F_N....	1 45 30	.....	.....	.....	.....	
20	.....	P.....	18 40 38	.....	.....	.....	6,115	
		S.....	18 48 20	.....	.....	.....	.....	
		L_E....	18 56 14	.....	.....	.....	.....	
		L_N....	18 56 04	.....	.....	.....	.....	
		M_E....	19 00 04	.....	*500	.....	.....	
		M_N....	18 58 14	.....	.....	*1,200	.....	
		F_E....	19 30 00	.....	.....	.....	.....	
		F_N....	19 35 30	.....	.....	.....	.....	

* Trace amplitude.

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

PORTO RICO. *U. S. C. & G. S. Magnetic Observatory, Vieques.*

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 20	.....	eP_E....	18 44 42	.....	.....	.....	.....	Time marker on E–W not operating.
		eP_N....	18 42 54	.....	.....	.....	.....	
		eS_E....	18 51 36	8	.....	.....	.....	
		eS_N....	18 51 38	.....	.....	.....	.....	
		L_E....	19 03 50	30	.....	.....	.....	
		eL_N...	19 06 30	.....	.....	.....	.....	
		M_E....	19 04 54	16	40	.....	.....	
		M_N....	19 09 25	18	.....	30	.....	
		C_E....	19 16 00	14	.....	.....	.....	
		C_N....	19 13 00	16	.....	.....	.....	
		F_E....	19 52 00	.....	.....	.....	.....	
		F_N....	19 19 00	.....	.....	.....	.....	
31	.....	P_E....	23 13 22	.....	.....	.....	.....	Probably near by.
		P_N....	23 13 22	.....	.....	.....	.....	
		L_E....	23 13 41	.....	.....	.....	.....	
		L_N....	23 13 45	.....	.....	.....	.....	
		M_E....	23 14 32	.....	10	.....	.....	
		M_N....	23 14 28	.....	.....	10	.....	
		C_E....	23 15 25	.....	.....	.....	.....	
		C_N....	23 15 35	.....	.....	.....	.....	
		F.....	23 19 00	.....	.....	.....	.....	

VERMONT. *U. S. Weather Bureau, Northfield.*

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 20	.....	e.....	18 53 00	.....	.....	.....	.....	
		eL.....	19 09 00	.....	.....	.....	.....	
		F.....	19 25 00	.....	.....	.....	.....	
23	.....	e.....	15 34 00	.....	.....	.....	.....	
		F.....	15 45 00	.....	.....	.....	.....	
29	.....	P?.....	5 16 25	.....	.....	.....	.....	
		S?.....	5 21 53	.....	.....	.....	.....	
		L.....	5 28 12	15	.....	.....	.....	
		F.....	6 20 ca.	.....	.....	.....	.....	

CANADA. *Dominion Observatory, Ottawa.*

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 9	.....	L.....	4 52 00	.....	.....	.....	.....	
		F.....	5 10 00	.....	.....	.....	.....	
10	.....	e_N.....	16 27 14	.....	.....	.....	.....	
		e.....	16 27 52	.....	.....	.....	.....	
		L_E....	16 28 48	.....	.....	.....	.....	
		F.....	16 33 00	.....	.....	.....	.....	
15	.....	O.....	12 16 43	.....	.....	.....	9,860	
		eP_E...	12 29 38	.....	.....	.....	.....	
		e_E....	12 35 42	.....	.....	.....	.....	
		eS_E...	12 40 30	.....	.....	.....	.....	
		L_E....	13 00 00	32	.....	.....	.....	
		L.....	13 06 00	22	.....	.....	.....	
		L.....	13 09 00	18	.....	.....	.....	
		L.....	13 17 00	17	.....	.....	.....	
		L.....	13 24 00	.....	.....	.....	.....	
		F.....	13 45 00	.....	.....	.....	.....	
19	.....	$e?_E$....	17 52 22	.....	.....	.....	.....	
		e.....	17 53 36	.....	.....	.....	.....	
	.....	i.....	17 54 22	.....	.....	.....	.....	
		L?.....	17 56 44	.....	.....	.....	.....	
20	.....	e.....	18 00 52	.....	.....	.....	.....	
		e.....	18 07 30	.....	.....	.....	.....	
		eL?...	18 09 42	.....	.....	.....	.....	
20	.....	O.....	18 31 23	.....	.....	.....	9,560	
		P_N....	18 44 04	.....	.....	.....	.....	
		S.....	18 54 42	.....	.....	.....	.....	
		S_{2E}...	19 00 30	.....	.....	.....	.....	
		eL?...	19 09 to					
		L.....	19 17	35	.....	.....	.....	L waves too soon by almost 3 minutes.
		L.....	19 18 to					
			19 21	18	.....	.....	.....	
		L.....	19 24 to					
			19 32	.....	.....	.....	.....	
		F.....	20 55 00	.....	.....	.....	.....	
22	.....	L.....	2 42 to					
			2 47	.....	.....	.....	.....	Irregular L waves.
		L.....	2 50 to					
			3 05	.....	.....	.....	.....	
		L.....	3 06 to					
		F.....	3 10	.....	.....	.....	.....	
22	.....	$e?_E$....	20 30 04	.....	.....	.....	.....	
		$e?_E$....	20 43 36	.....	.....	.....	.....	
		L.....	20 55 to					
			20 58	30	.....	.....	.....	
		L.....	20 59 to					
			21 10	22	.....	.....	.....	
		Le.....	21 15 to					
			21 20	16	.....	.....	.....	
		F.....	21 40	.....	.....	.....	.....	

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

CANADA. *Dominion Observatory, Ottawa*—Continued.

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar 23	.....	O.....	15 21 53	.....	.....	.....	3,400	
		iP?....	15 28 25	.....	.....	.....	.....	
		iS?....	15 33 35	.....	.....	.....	.....	
		L.....	15 36 30	.....	.....	.....	.....	
		F.....	16 15	.....	.....	.....	.....	
29	.....	O.....	5 07 50	.....	.....	.....	3,780	Wellmarked quake, but small and irregular L waves after M.
		P.....	5 14 55	.....	.....	.....	.....	
		S.....	5 20 36	.....	.....	.....	.....	
		L.....	5 25	.....	.....	.....	.....	
		M.....	5 27 to 5 31	.....	.....	.....	.....	
		L.....	5 35 to 5 45	42	.....	.....	.....	
		F.....	6 45	.....	.....	.....	.....	

CANADA. *Dominion Meteorological Service, Toronto.*

1920			H. m. s.	Sec.	μ	μ	Km.	
Mar. 9	.....	L.....	4 51 54	.....	*50	.....	.....	
10	.....	L.....	16 32 12	.....	*50	.....	.....	Micros going on.
12	.....	L.....	16?27 54	.....	*100	.....	.....	Do.
12	.....	L.....	18 31 18	.....	.....	.....	.....	Do.
		L.....	18 37 12	.....	*200	.....	.....	
13	.....	eL.....	5 04 48	.....	.....	.....	.....	
		M.....	5 07 54	.....	*300	.....	.....	
		F.....	.....	.....	.....	.....	.....	Micros.
15	.....	P?.....	12 25 06	.....	.....	.....	.....	
		e.....	12 31 12	.....	.....	.....	.....	
		S.....	12 34 42	.....	.....	.....	.....	
		e.....	12 39	.....	.....	.....	.....	
		L.....	13 02 06	.....	.....	.....	.....	
		eL.....	13 04 42	.....	.....	.....	.....	
		M.....	13 11 48	.....	*2,400	.....	8,330	
		F.....	14 23 06	.....	.....	.....	.....	
20	.....	eL.....	0 07 36	.....	.....	.....	.....	
		M.....	0 08 30	.....	*200	.....	.....	
		F.....	0 10 42	.....	.....	.....	.....	
20	.....	S?.....	18 09 36	.....	.....	.....	.....	Inspecting instrument at first phase. Possibly West Indies.
		L.....	18 12 24	.....	.....	.....	.....	
		M.....	.....	.....	*200	.....	.....	
		F.....	18 22 12	.....	.....	.....	.....	
20	.....	P.....	18 42 48	.....	.....	.....	11,330	Approximate Lat. 23° 40 S., Long. 163° W.
		iS.....	18 54 48	.....	.....	.....	.....	
		L.....	19 07 36	.....	.....	.....	.....	
		eL.....	19 17 12	.....	.....	.....	.....	
		M.....	19 18 36	.....	*1,400	.....	.....	
		eL.....	19 32	.....	.....	.....	.....	
		eL.....	19 43	.....	.....	.....	.....	
		M2.....	19 48	.....	*1,000	.....	.....	
		L_{rEp}..	20 45 30	.....	*200	.....	.....	
		L?.....	20 54 12	.....	.....	.....	.....	
		F?.....	20 59 18	.....	.....	.....	.....	
22	.....	L.....	2 00 42	.....	.....	.....	.....	
		L.....	2 20 30	.....	.....	.....	.....	
		L.....	2 49 12	.....	.....	.....	.....	
		L.....	3 27 36	.....	*200	.....	.....	Abnormal L waves.
22	.....	S?.....	20 42 18	.....	.....	.....	.....	
		L.....	20 58 30	.....	.....	.....	.....	
		eL.....	21 02 06	.....	.....	.....	.....	
		M.....	21 05 42	.....	*500	.....	.....	
		F.....	21?40 48	.....	.....	.....	.....	
23	.....	P.....	15?25 12	.....	.....	.....	.....	
		S.....	15 32 18	.....	.....	.....	.....	
		i.....	15 34 24	.....	.....	.....	.....	
		L.....	15 36 24	.....	.....	.....	.....	
		eL.....	15 41 06	.....	.....	.....	.....	
		M.....	15 45 36	.....	*700	.....	5440?	
		F.....	16 16 12	.....	.....	.....	.....	
29	.....	S.....	5 20 36	.....	.....	.....	.....	P not recorded.
		eL.....	5 26 00	.....	.....	.....	.....	
		iL.....	5 26 42	.....	.....	.....	.....	
		M.....	5 27 30	.....	*2,200	.....	.....	Very irregular movements between two maxima.
		iL.....	5 30 00	.....	.....	.....	.....	
		M2.....	5 30 12	.....	*2,200	.....	.....	
		F.....	6?21 54	.....	.....	.....	.....	

* Trace amplitude.

TABLE 2.—*Instrumental reports, March, 1920*—Continued.

CANADA. *Dominion Meteorological Service, Victoria.*

1920.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 9	.....	M.....	4 51 35	.....	*200	.....	.....	
11	.....	M.....	12 53 44	.....	*50	.....	.....	
11	.....	M.....	19 20 49	.....	*50	.....	.....	
12	.....	M.....	16 05 46	.....	*200	.....	.....	
		L.....	16 26 54	.....	.....	.....	.....	
12	.....	S?orL.	18 17 34	.....	.....	.....	.....	
		M.....	18 27 24	.....	*300	.....	.....	
		L.....	18 37 43	.....	.....	.....	.....	
13	.....	L?.....	4 40 43	.....	.....	.....	.....	
		M.....	4 47 36	.....	*300	.....	.....	
15	.....	P.....	12 19 25	.....	.....	.....	7,420	Probably Japan or Peru.
		S.....	12 28 16	.....	.....	.....	.....	
		L.....	12 39 35	.....	.....	.....	.....	
		M.....	12 48 55	.....	*500	.....	.....	
		F.....	13 28 16	.....	.....	.....	.....	
20	.....	L?.....	0 03 17	.....	.....	.....	.....	
		M.....	0 14 06	.....	*300	.....	.....	
		F.....	?0 23 56	.....	.....	.....	.....	
20	.....	L.....	17 42 39	.....	.....	.....	.....	
		M.....	17 43 38	.....	*200	.....	.....	
20	.....	L.....	17 52 00	.....	.....	.....	.....	
		M.....	17 53 28	.....	*1,000	.....	.....	
		F.....	18 24 28	.....	.....	.....	.....	
20	.....	P.....	18 45 07	.....	.....	.....	8,000	Do.
		S.....	18 54 27	.....	.....	.....	.....	
		L.....	19 06 16	.....	.....	.....	.....	
		M.....	19 14 38	.....	*2,000	.....	.....	
		L_{rEp}..	21 05 23	.....	.....	.....	.....	
		F.....	21 21 17	.....	.....	.....	.....	
22	.....	M.....	0 06 22	.....	*100	.....	.....	
		F.....	0 18 10	.....	.....	.....	.....	
22	.....	M.....	2 23 05	.....	*300	.....	.....	
		F.....	2 41 46	.....	.....	.....	.....	
22	.....	P?.....	20 22 10	.....	.....	.....	.....	
		L.....	20 36 26	.....	.....	.....	.....	
		M.....	20 43 10	.....	*400	.....	.....	
		F.....	21 07 28	.....	.....	.....	.....	
23	.....	P.....	15 35 16	.....	.....	.....	.....	
		L.....	15 43 11	.....	.....	.....	.....	
		M.....	15 46 40	.....	*400	.....	.....	
		F.....	15 59 34	.....	.....	.....	.....	
29	.....	P.....	5 09 15	.....	.....	.....	.....	
		L.....	5 09 44	.....	.....	.....	.....	
		M.....	5 11 13	.....	*17,500	.....	220	
		F.....	5 17 36	.....	.....	.....	.....	
				VERTICAL.				
		P.....	*5 09 04*	*2–5*	.....	.....	630	Probably in east Washington or west Montana.
		L.....	*5 10 29*	*10*	.....	.....	.....	
		M.....	*5 10 59*	*15*	.....	.....	.....	

* Trace amplitude.

The following stations recorded no earthquakes during March, 1920:

CALIFORNIA. *Theosophical University, Point Loma.*
ALABAMA. *Spring Hill College, Mobile.*

Reports for March, 1920, have not been received from the following stations:

ALASKA. *U. S. C. & G. S. Magnetic Obeservatory, Sitka.*
HAWAII. *U. S. C. & G. S. Magnetic Observatory, Honolulu.*
KANSAS. *University of Kansas, Lawrence.*
MISSOURI. *St. Louis University, St. Louis.*
NEW YORK. *Canisius College, Buffalo;* Fordham University, *New York.*

For the reports of the stations at the University of California, Berkeley, Calif., and at the Lick Observatory, Mount Hamilton, Calif., see *Bulletin of the Seismographic*

Stations, University of California. For the report of the University of Santa Clara Station, see *Record of the the Seismographic Stations, University of Santa Clara.*

SEISMOLOGICAL DISPATCHES.[1]

Jiguero Light Station, San Juan, P. R., January 27, 1920.

Yesterday at 5:10, 6:50, and 8:08 p. m., three earthquakes were felt, lasting 4, 6, and 7 seconds respectively.—*Special Observer (belated dispatch).*

Jiguero Light Station, San Juan, P. R., February, 11, 1920.

An earthquake that lasted from 11 to 12 seconds was felt here yesterday.—*Special Observer (belated dispatch).*

Redondo Beach, Calif., March 3, 1920.

A sharp earthquake shock was felt here and at Manhattan Beach and El Segundo at 7:25 o'clock to-night. The quake lasted several seconds. No damage was done.—*Associated Press.*

Tiflis, February 24, via Constantinople, March 8, 1920.

Several hundred persons are dead and thousands of others are homeless as the result of an earthquake to-day which destroyed Grakali and other villages within a radius of sixty miles west of Tiflis.—*Associated Press.*

Fort de France, Martinique, March 21, 1920.

A rather strong earth shock was felt here early this morning. No damage was done.—*Associated Press.*

LATE REPORTS (INSTRUMENTAL).

CANAL ZONE. *Department of Operation and Maintenance, Balboa Heights.*

1920			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Jan. 4								Slight tremors from distant quake, beginning 4-26-56. Probably disturbance in Mexico.
9		P	16 23 56				547	Dir. probably NW.
		S	16 24 54					
		M_N	16 24 56			*7,000		
		M_E	16 24 58		*4,000			
		F_N	16 32 20					
		F_E	16 31 30					
26		P	22 26 00				77	Probably W. or SW.
		S	22 26 09					Generally felt.
		M_N	22 26 11			*3,500		
		M_E	22 26 12		*4,500			
		F_N	22 27 40					
		F_E	22 27 45					
30		P_N	18 28 14				869	Probably NW.
		P_E	18 24 14					
		S_W	18 29 48					
		S_E	18 29 46					
		L_N	18 30 16					
		L_E	18 30 14					
		M_N	18 31 08			*15,000		
		M_E	18 30 38		*13,000			
		F_N	18 58 20					
		F_E	18 53 00					

* Trace amplitude.

[1] Reported by the organization indicated, and collected by the Seismological Station, Georgetown University, Washington, D. C.

DISTRICT OF COLUMBIA. *Georgetown University.*

1920			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Feb. 2		e_E	11 40 00					e possibly sooner; heavy micros; apparently two quakes overlapping.
		e_N	11 40 00					
		S_E?	11 48 45					
		eL_E?	12 04 42	17				
		eL_N	12 05 12	17				
		L_E	12 27 ..	25				
		L_N	12 26 23	26				
		M_{E1}	12 37 09	24	*1,000			
		M_N	12 35 00	24		*700		
		M_{E2}	12 41 16	16	*900			
		F	14 *ca*					
7		eL_E	12 09 36	16				Very heavy micros; first phases lost in above.
		L_N	12 10 21	21				
		F	12 20 ..					
7								Sheets put on at 13h 30m. Very heavy micros; suspicion of quake; impossible to evaluate.
10		iP	22 12 10					
		iS	22 16 15					
		eL_E	22 17 30	15				
		eL_N	22 17 24	15				
		L_E	22 20 25	19				
		L_N	22 19 10	18				
		M_E	22 26 06	14	*4,100			
		M_N	22 26 10	14		*3,000		
11		F	0 10 ..					
			VERTICAL.					
10		P_Z	*22-12-10*					
		S_Z	*22 16 16*					
		eL_Z	*22 17 24*	*19*				
		L_Z	*22 19 10*	*19*				
		F	*25 ca.*					
12		eP_E	0 31 18					
		eP_N	0 31 18					
		S	0 35 18					
		L_E	0 40 11	11				
		L_N	0 40 00	11				
		F	0 50 ..					
12		e_E	17 54 10					Heavy micros.
		e_N	17 53 59					
		L_N	18 06 17	24				
		F	18 10 ..					
22		P_E	17 47 52					
		P_N	17 47 52					
		S	17 57 41					
		i_E	17 57 52					
		i_N	17 57 52					
		F	18 25 ..					
28		P_E	18 50 09					E–W component not so well defined; heavy micros.
		P_N	18 50 09					
		S	18 57 53					
		eL	19 05 06	7				
		L_E	19 14 20	19				
		L_N	19 14 31	22				
		F	19 20 ..					

* Trace amplitude.

Chart I. Hydrographs of Several Principal Rivers, March, 1920.

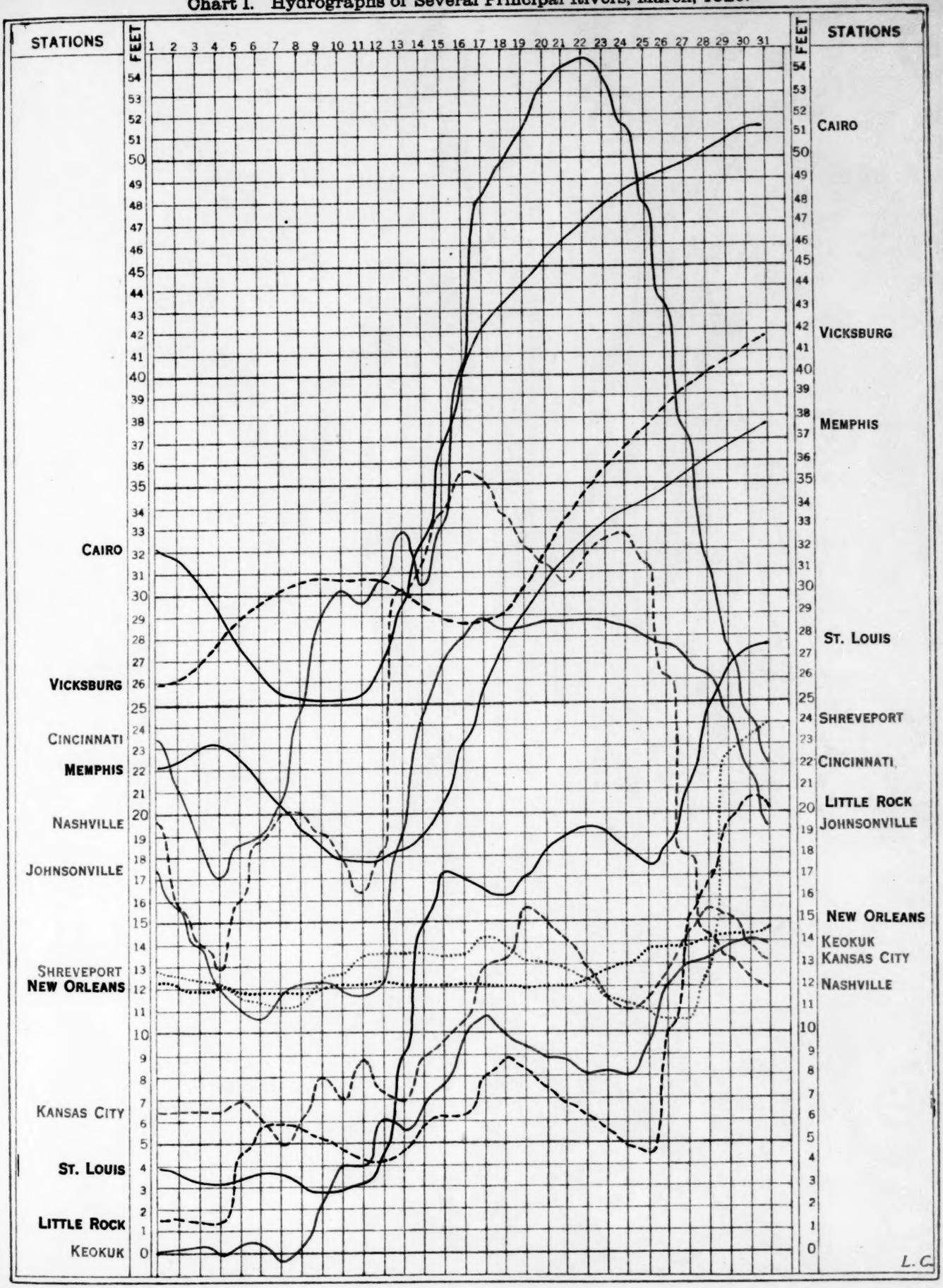

STATIONS
FEET
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
54 53 52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37 36 35 34 33 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
CAIRO
VICKSBURG
CINCINNATI
MEMPHIS
NASHVILLE
JOHNSONVILLE
SHREVEPORT
NEW ORLEANS
KANSAS CITY
ST. LOUIS
LITTLE ROCK
KEOKUK
STATIONS
CAIRO
VICKSBURG
MEMPHIS
ST. LOUIS
SHREVEPORT
CINCINNATI
LITTLE ROCK
JOHNSONVILLE
NEW ORLEANS
KEOKUK
KANSAS CITY
NASHVILLE
L.C.

Chart II. Tracks of Centers of High Areas, March, 1920.

(Plotted by R. H. Weightman, Meteorologist.)

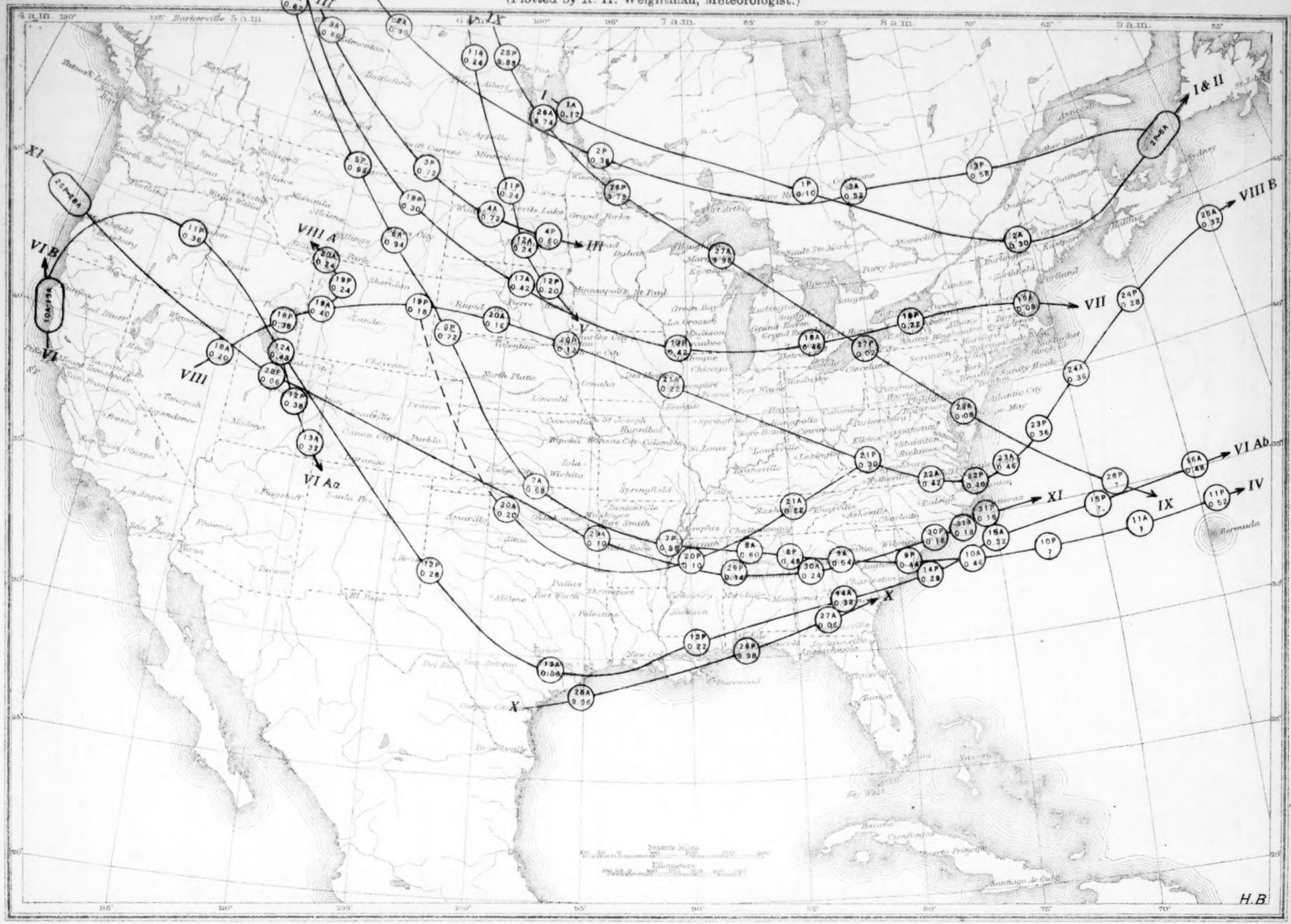


Chart III. Tracks of Centers of Low Areas, March, 1920.

Chart III. Tracks of Centers of Low Areas, March, 1920.

(Plotted by R. H. Weightman, Meteorologist.)

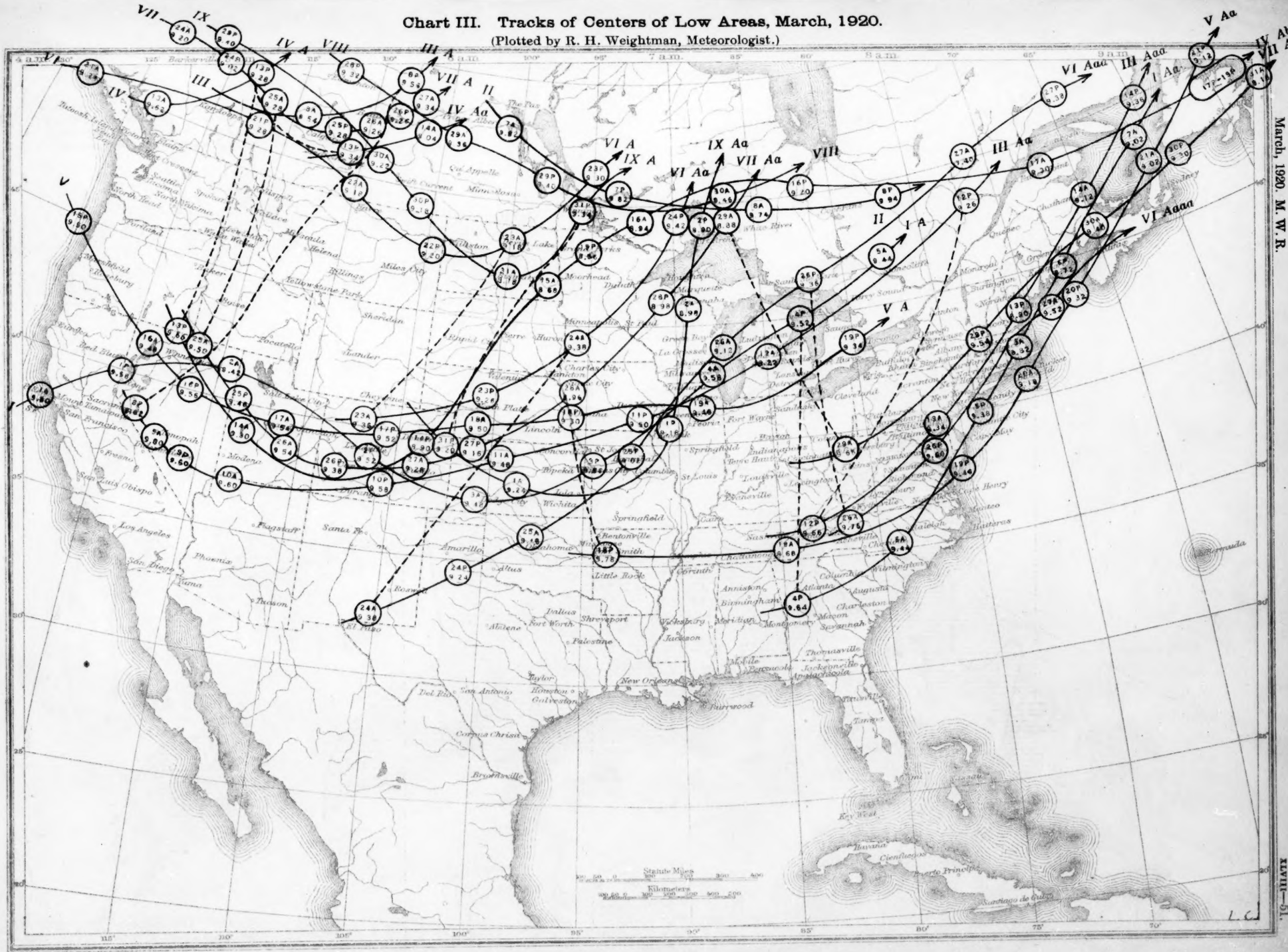


Chart IV. Departure (°F.) of the Mean Temperature from the Normal, March, 1920.

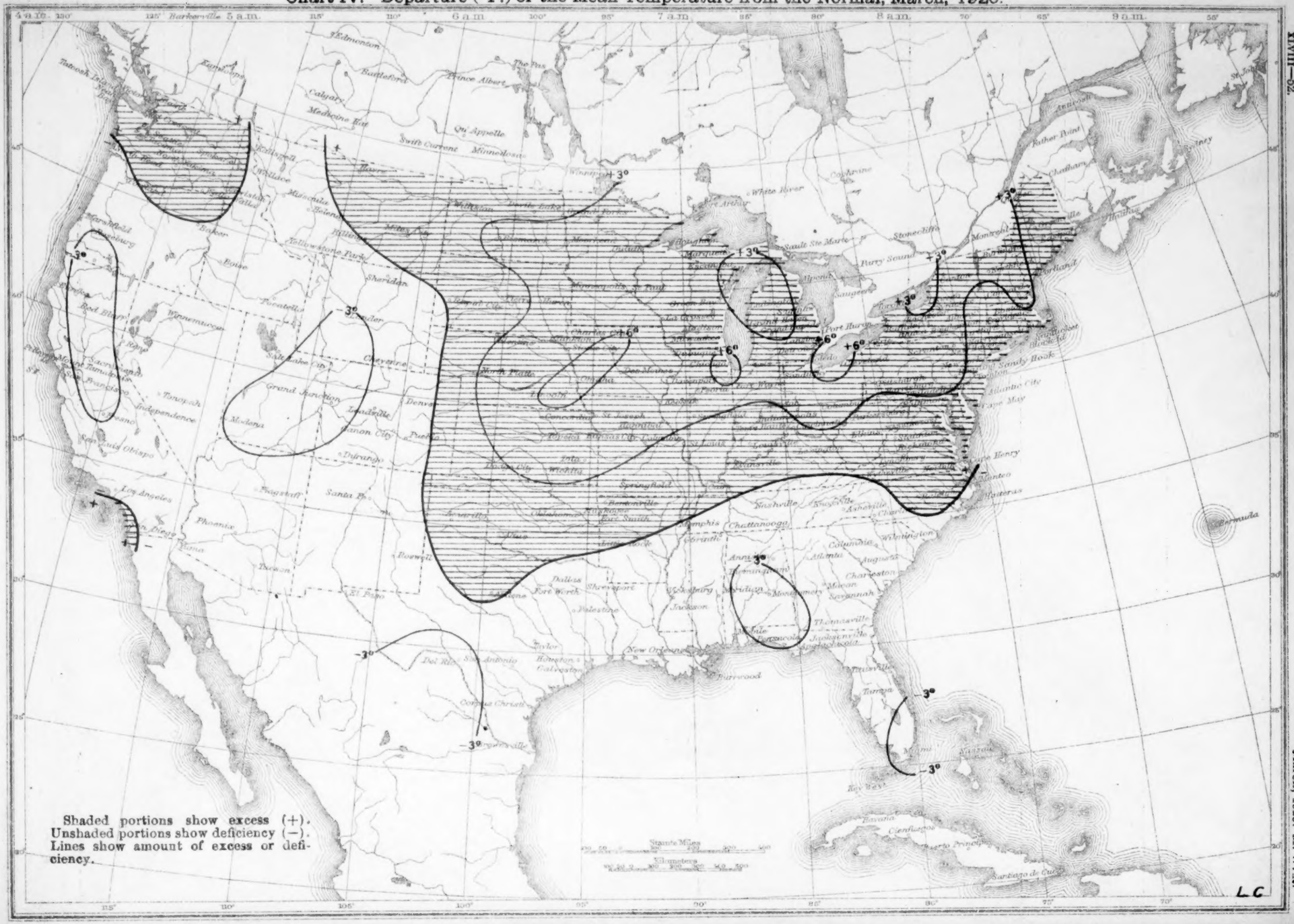


Chart V. Total Precipitation, Inches, March, 1920.

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, March, 1920.

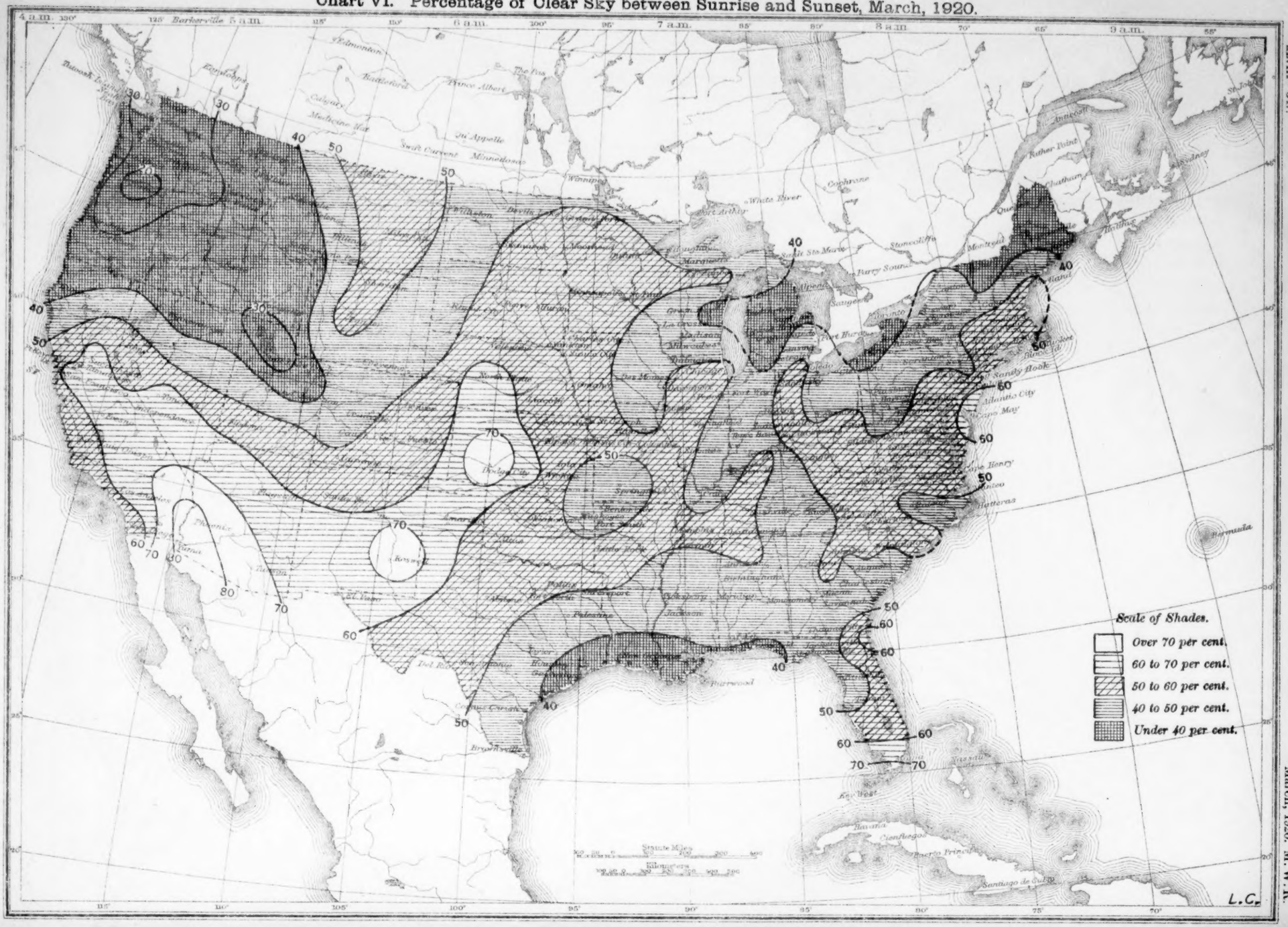


Chart VII. Isobars and Isotherms at Sealevel; Prevailing Winds, March, 1920.

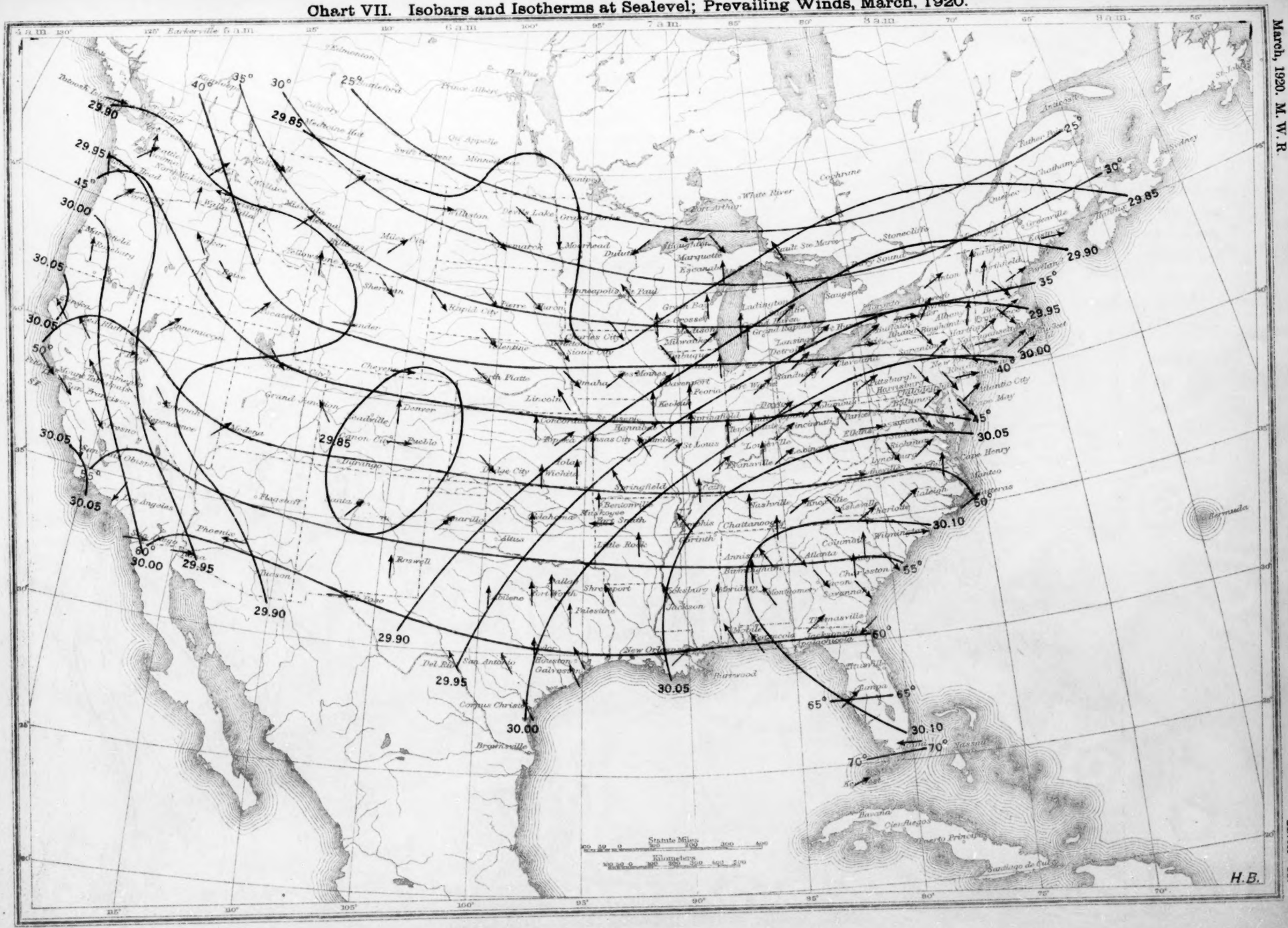


Chart VIII. Total Snowfall, Inches, March, 1920.

Chart IX. Weather Map of North Atlantic Ocean, March 14, 1920.

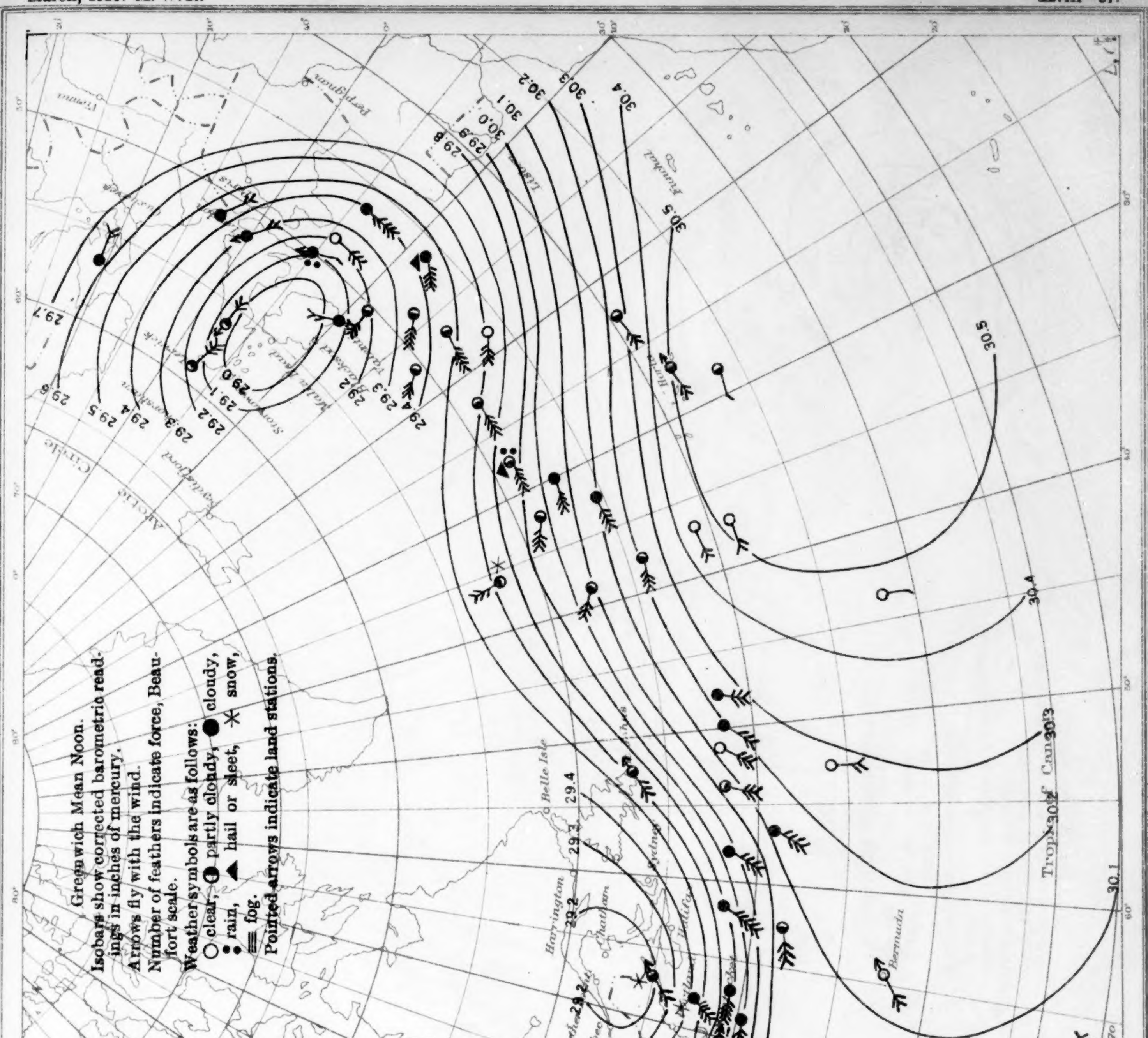


Chart IX. Weather Map of North Atlantic Ocean, March 14, 1920.
(Plotted by F. A. Young.)

Chart X. Weather Map of North Atlantic Ocean, March 15, 1920.

(Plotted by F. A. Young.)

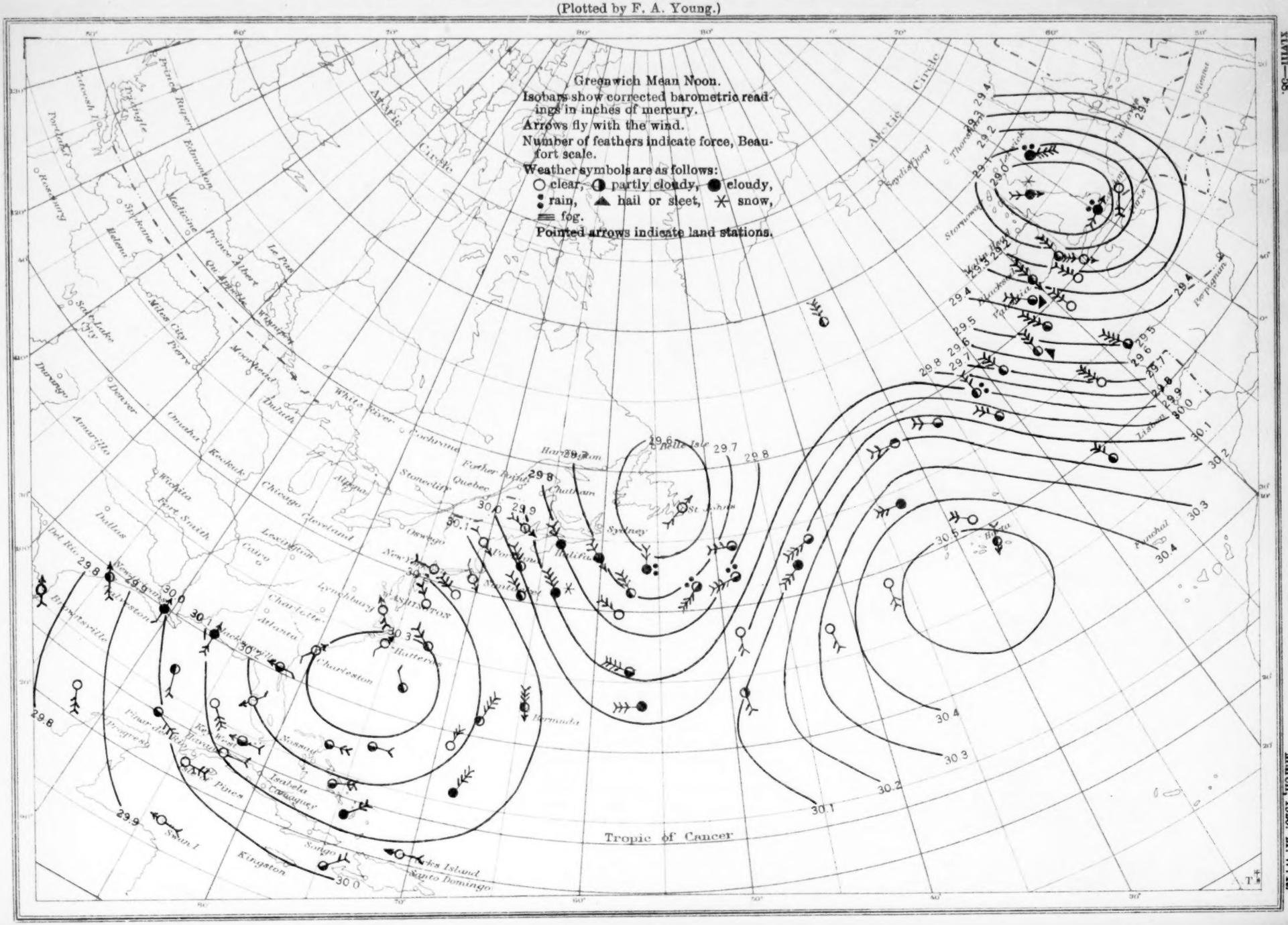


Chart XI. Weather Map of North Atlantic Ocean, March 24, 1920.

Chart XI. Weather Map of North Atlantic Ocean, March 24, 1920.

(Plotted by F, A. Young.)

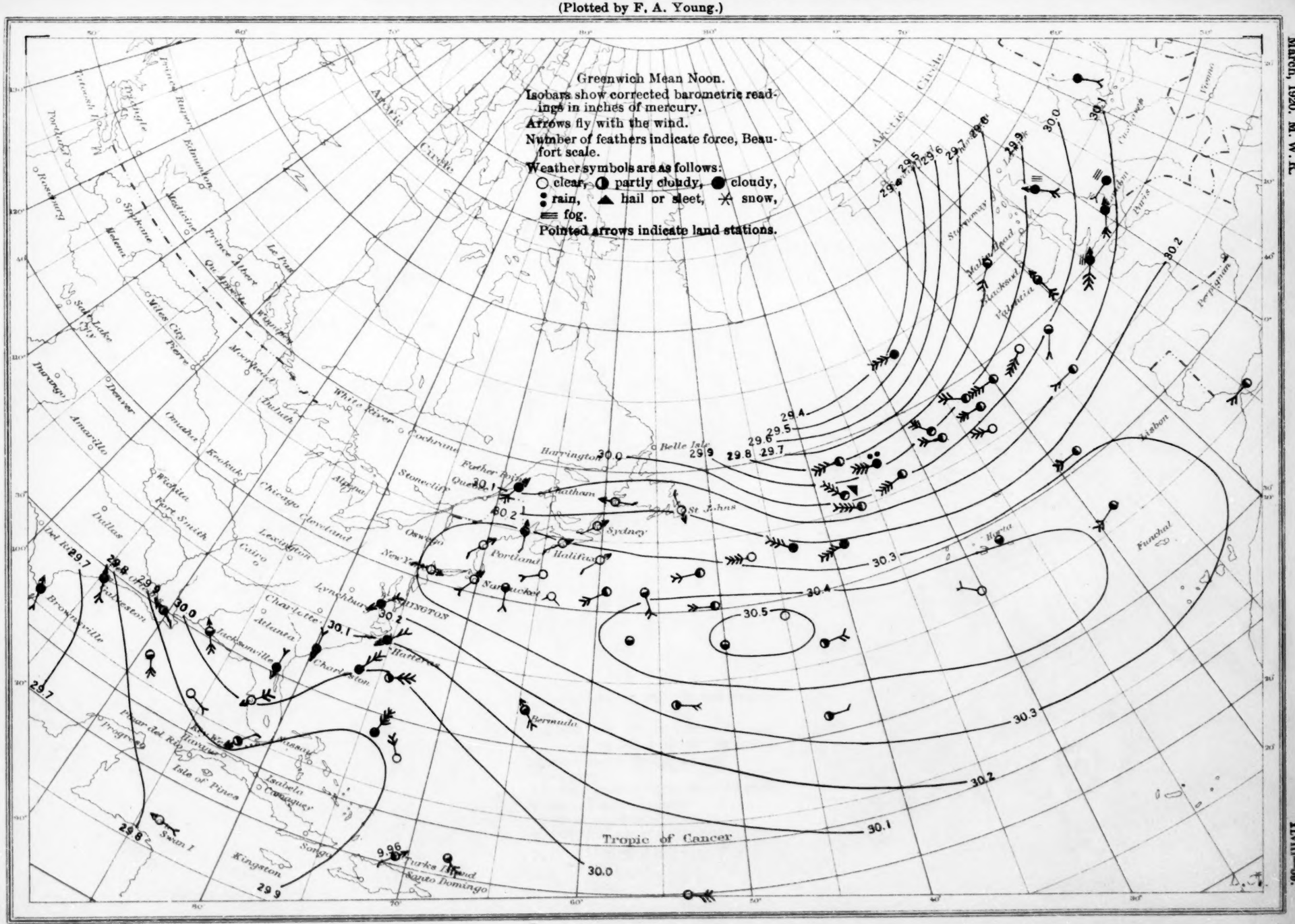


Chart XII. Weather Map of North Atlantic Ocean, March 25, 1920.

(Plotted by F. A. Young.)

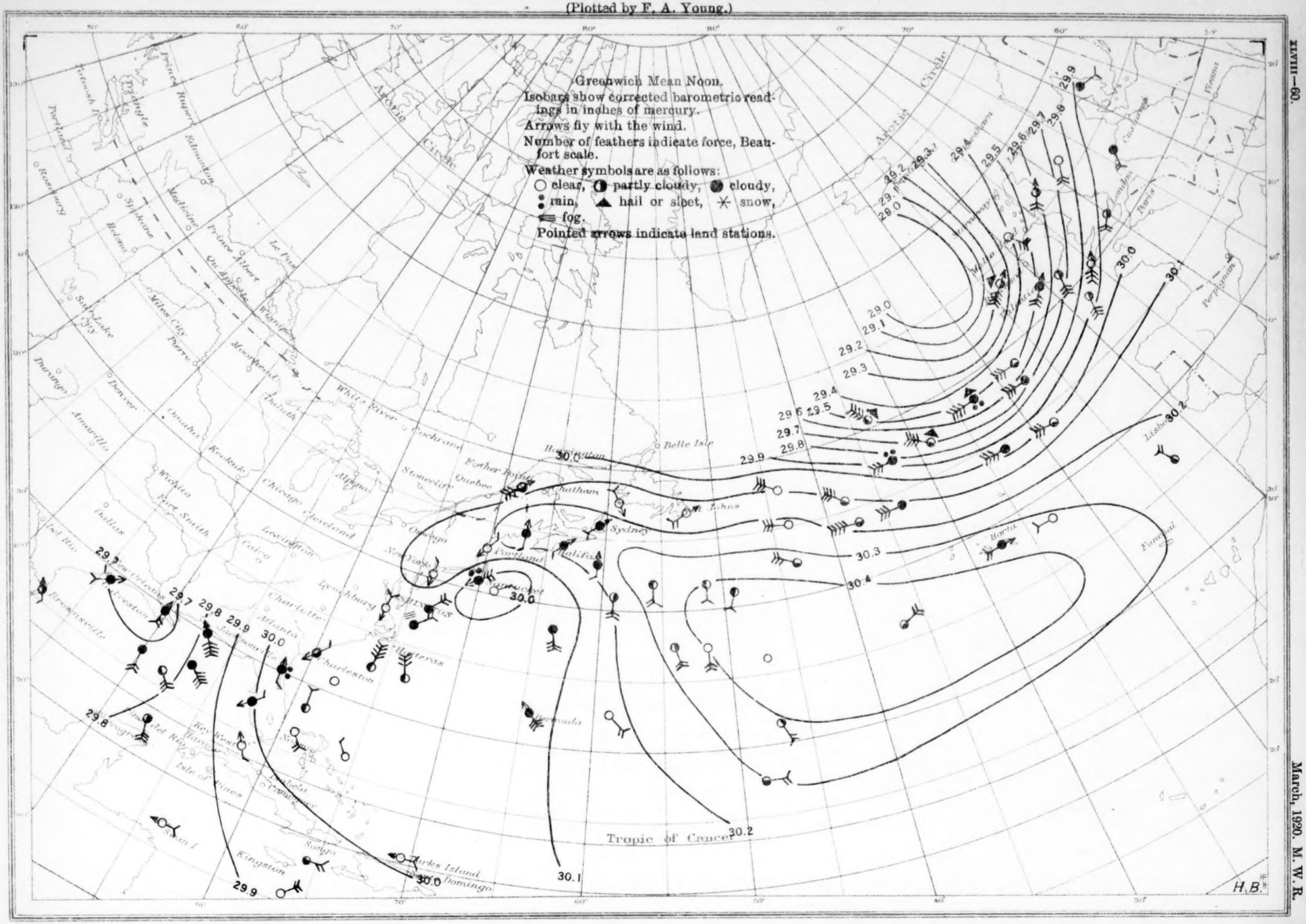

Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
clear, partly cloudy, cloudy,
rain, hail or sleet, snow,
fog.
Pointed arrows indicate land stations.
Arctic Circle
Tropic of Cancer
H.B.

Chart XIII. Weather Map of North Atlantic Ocean, March 26, 1920.

Chart XIII. Weather Map of North Atlantic Ocean, March 26, 1920.

(Plotted by F. A. Young.)

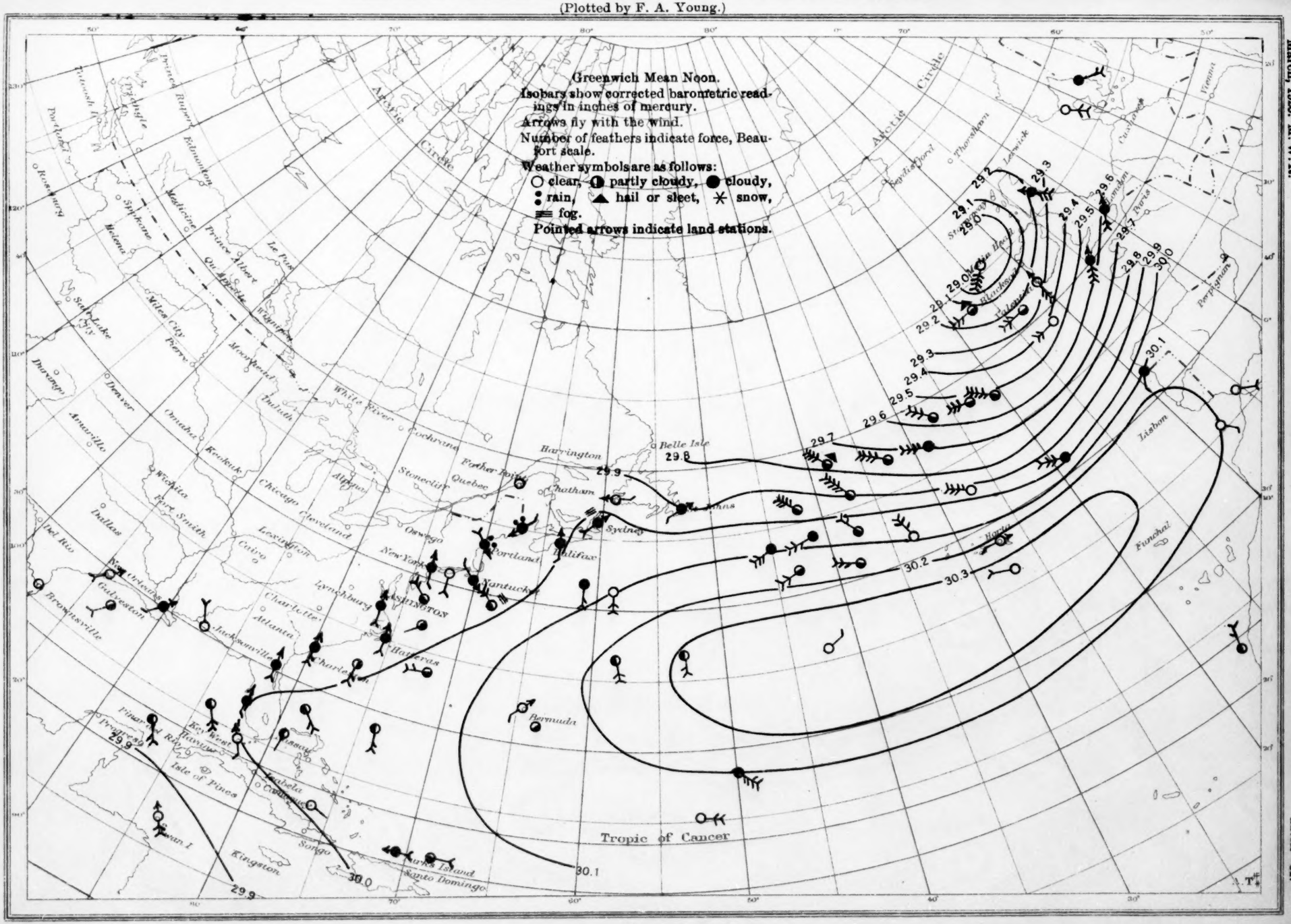
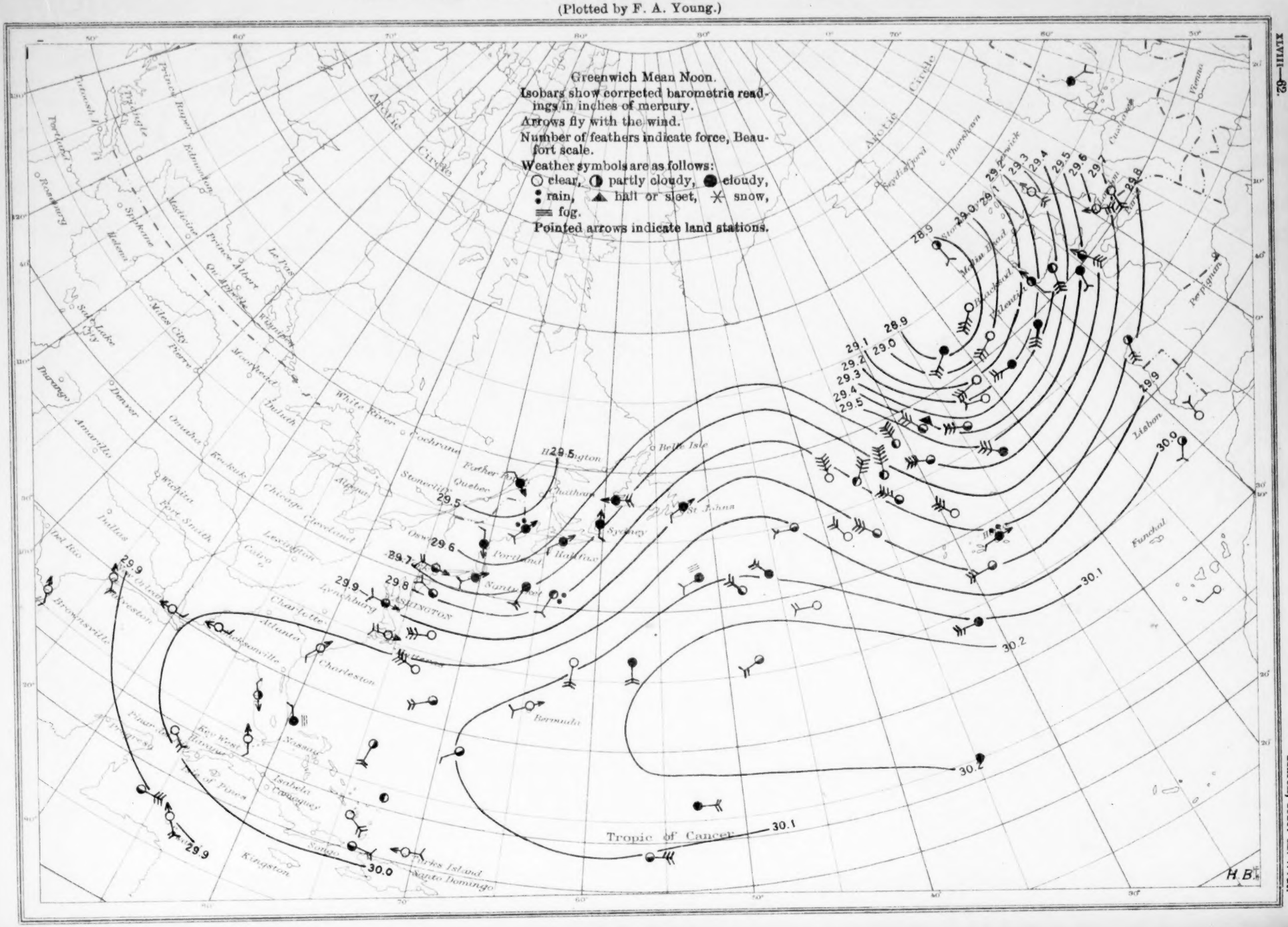


Chart XIV. Weather Map of North Atlantic Ocean, March 27, 1920.

(Plotted by F. A. Young.)